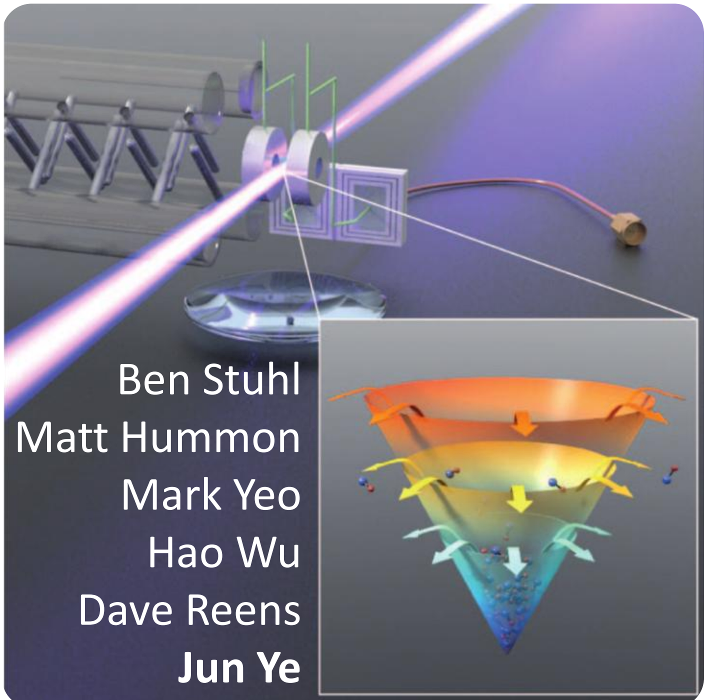
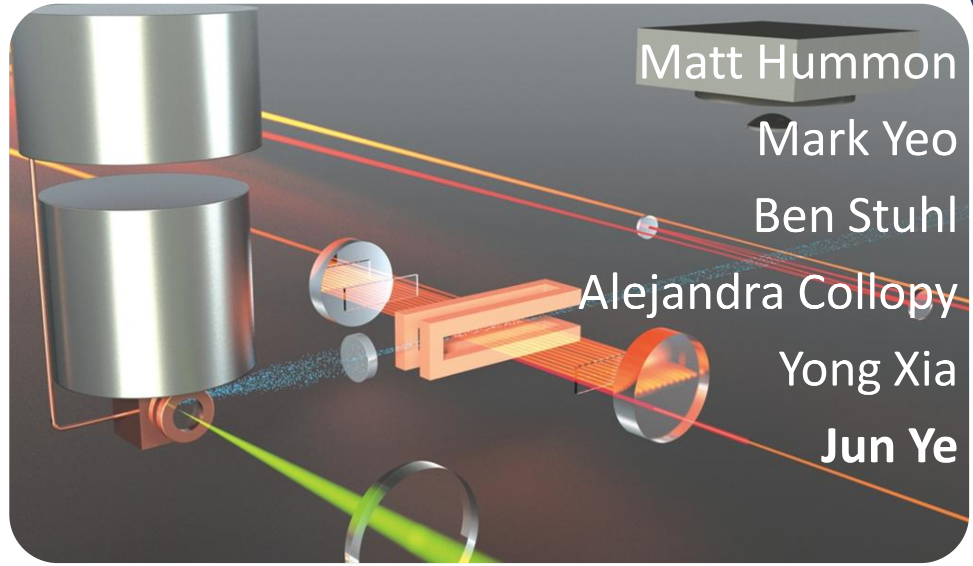
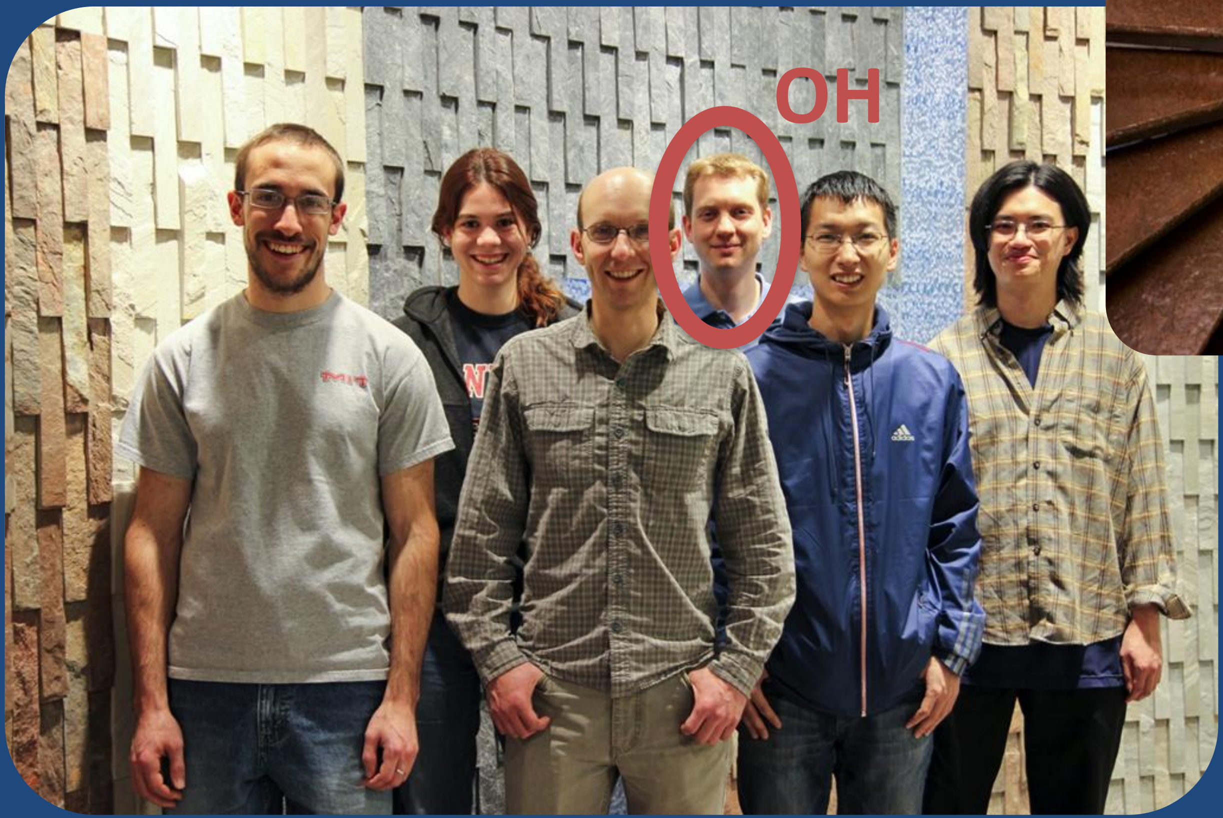
MOT and Evaporative cooling for polar molecules

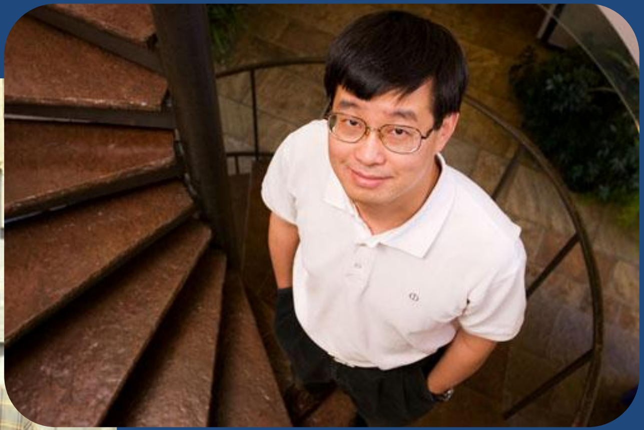




The Cold Molecule Team



Alejandra Collopy Ben Stuhl Mark Yeo
Dave Reens Matt Hummon Hao Wu



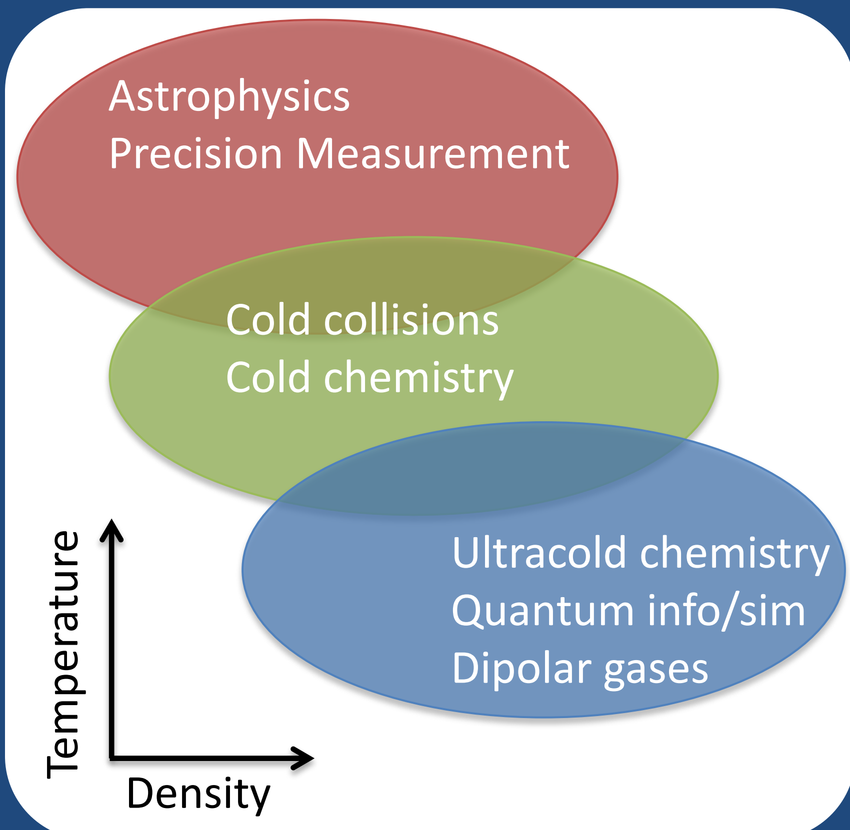
Jun Ye

Theory support

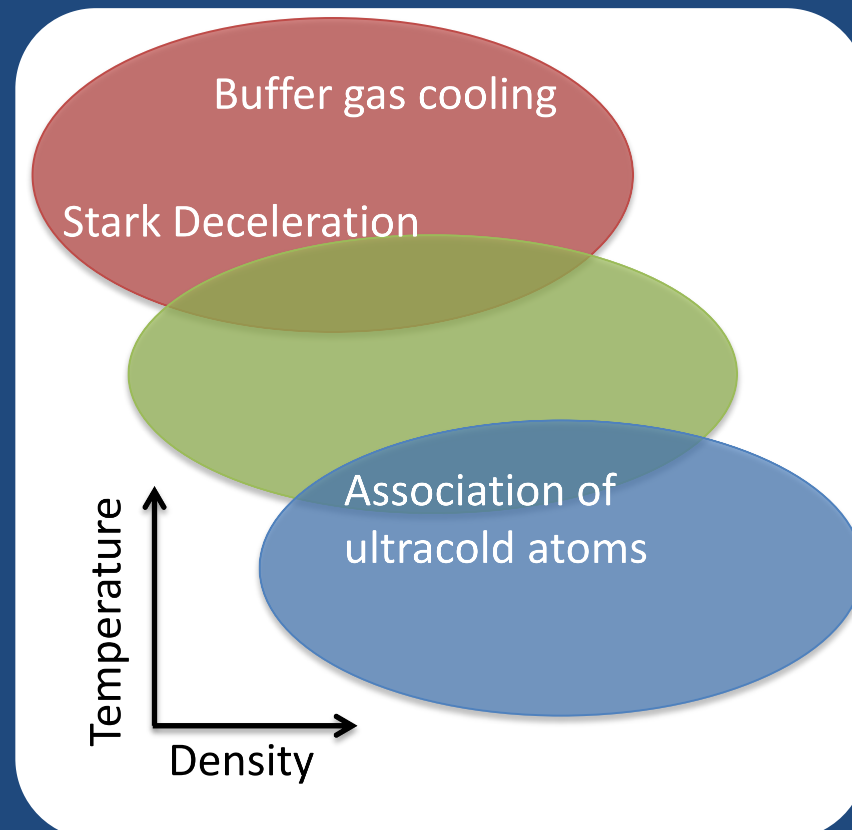
Goulven Quéméner
John Bohn

Cold Polar Molecules

Applications

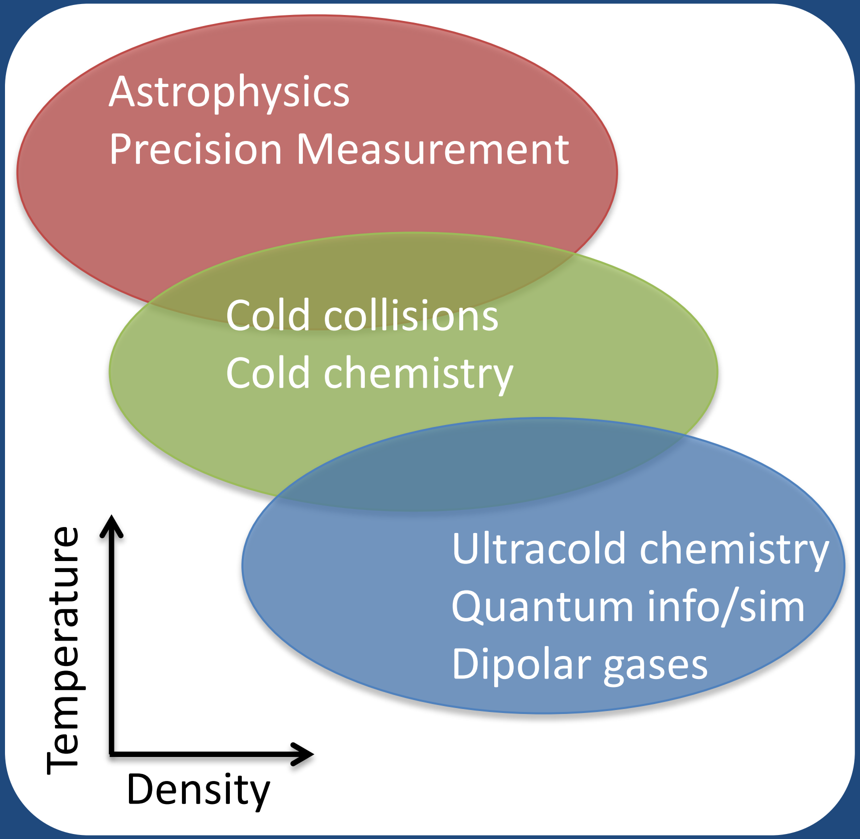


Techniques

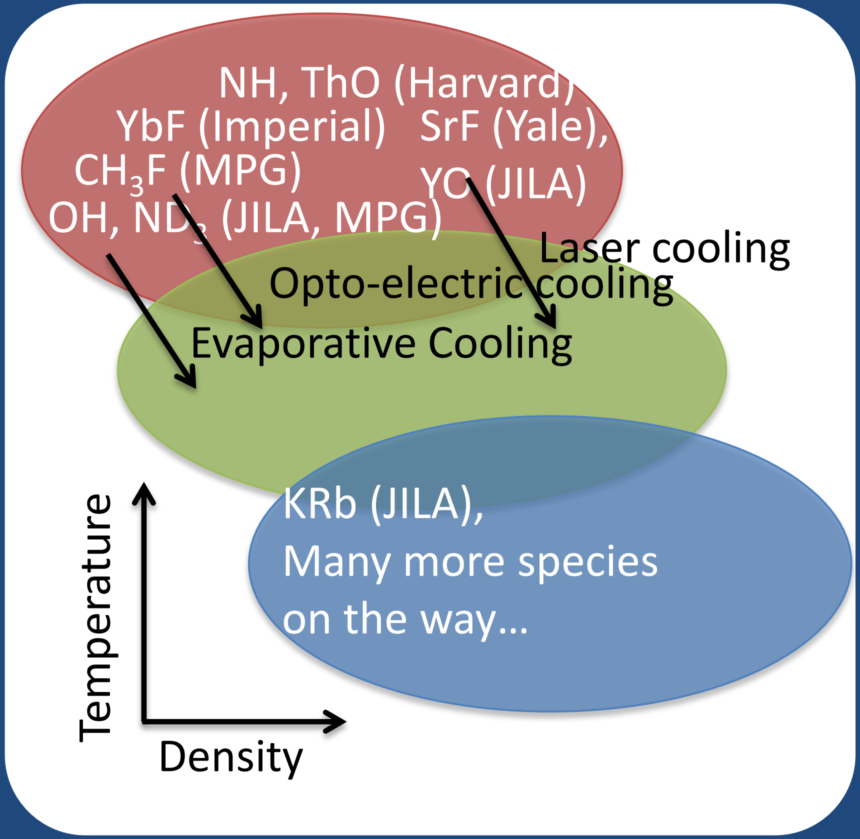


Cold Polar Molecules

Applications



Techniques

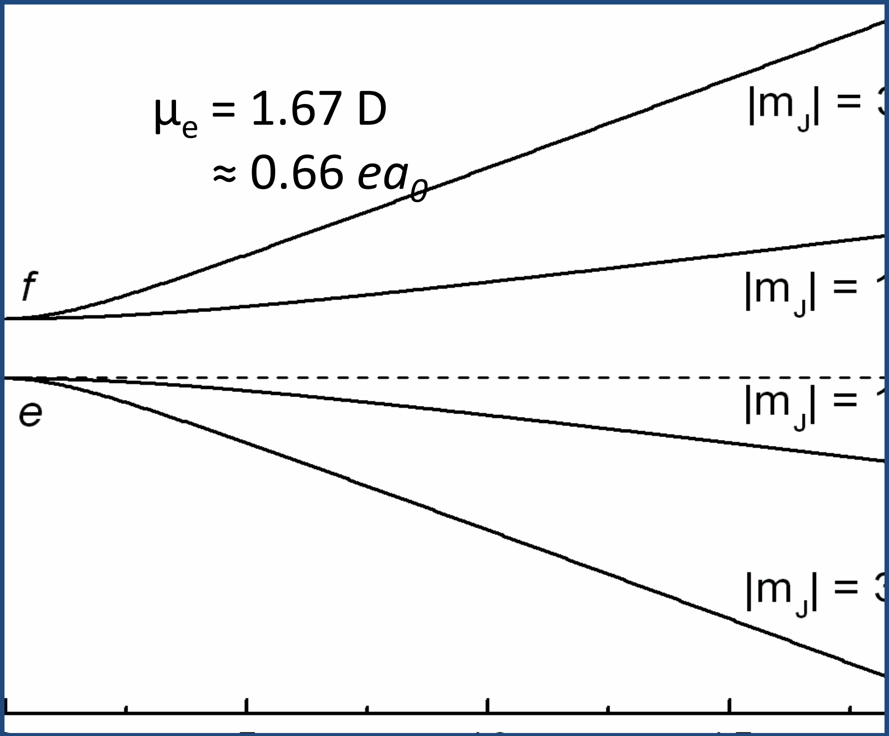


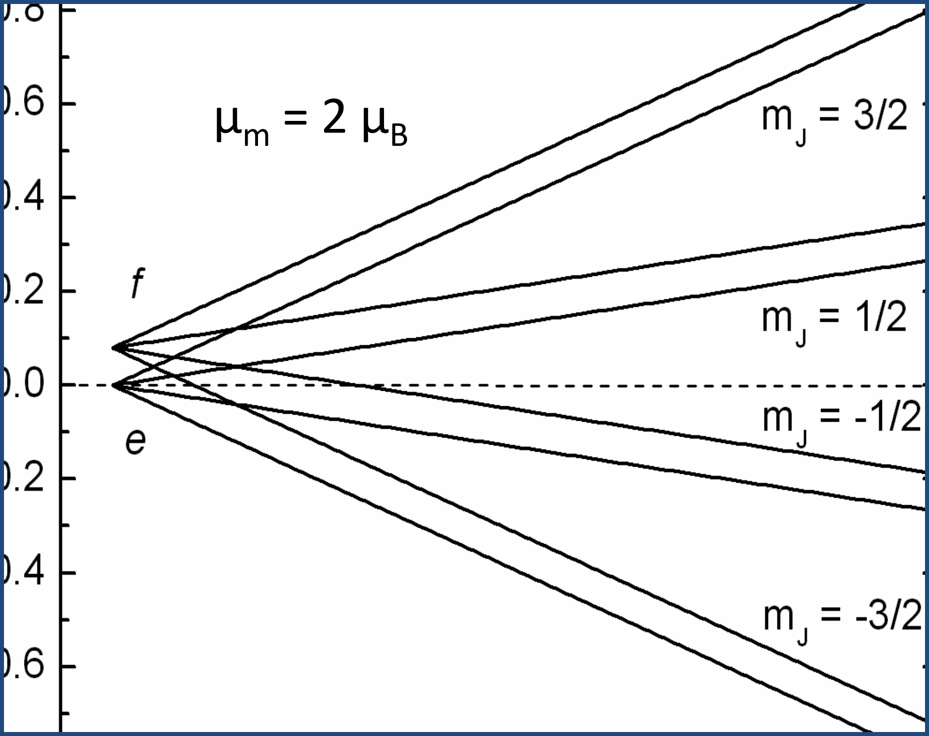
Outline

- Introduction to the OH molecule
  - Level Structure
  - Magnetic trapping apparatus
  - Internal state manipulation
- Collisions in OH
  - E-field induced inelastic 2-body loss
  - Elastic collisions and evaporation of OH

The OH molecule, Two Dipoles!

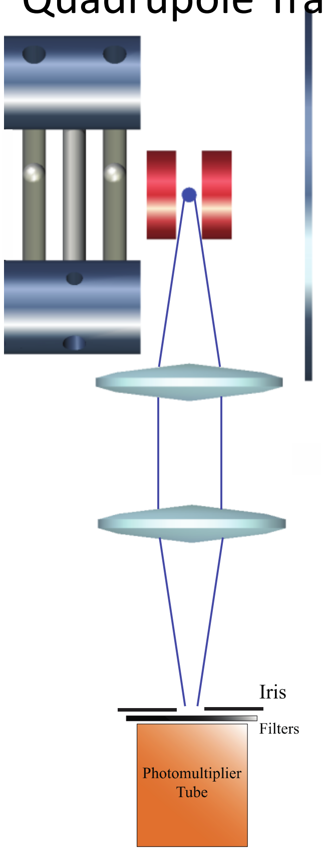
$X^2\Pi_{3/2}$, v = 0, J = 3/2

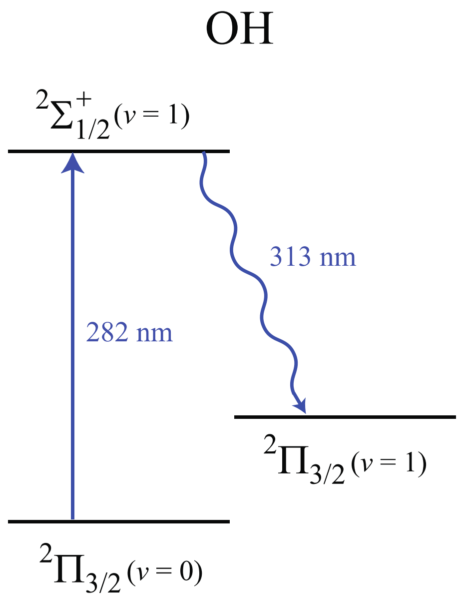




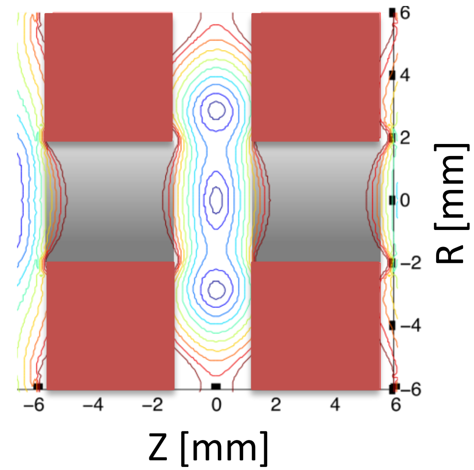
The OH apparatus

Permanent Magnet
Quadrupole Trap

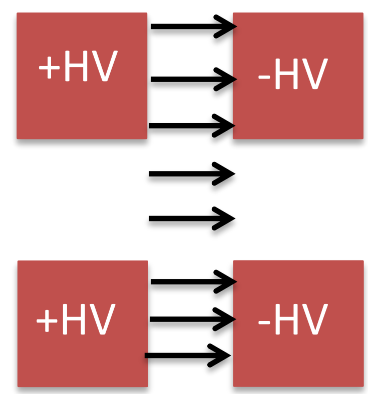




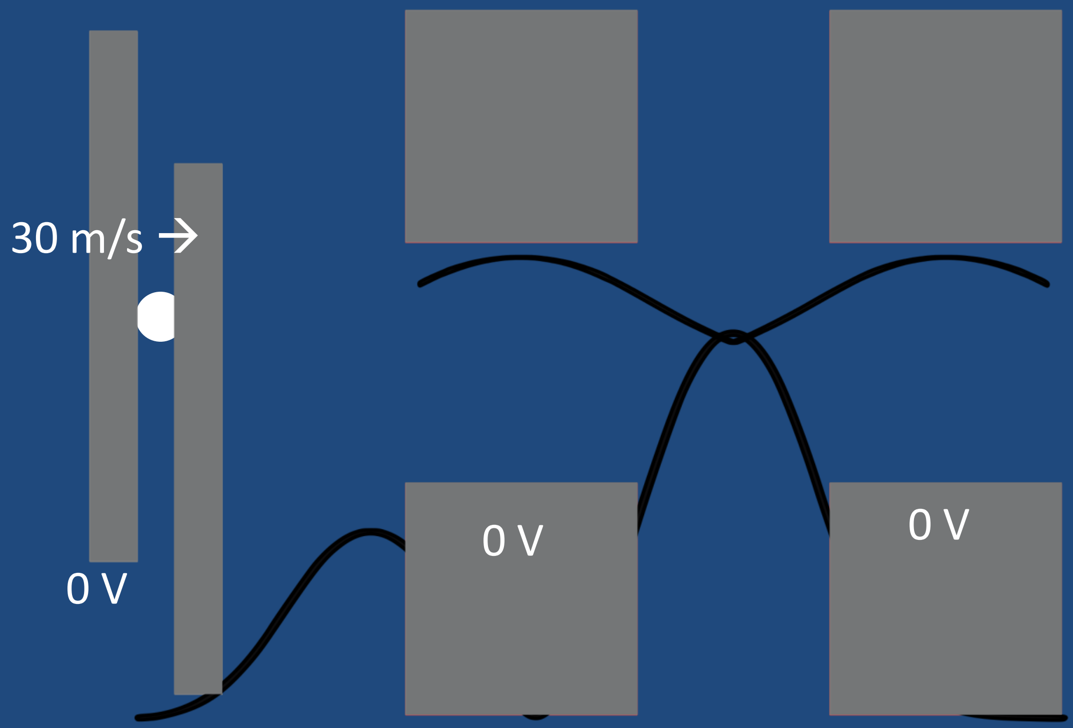
Magnetic Field Contours



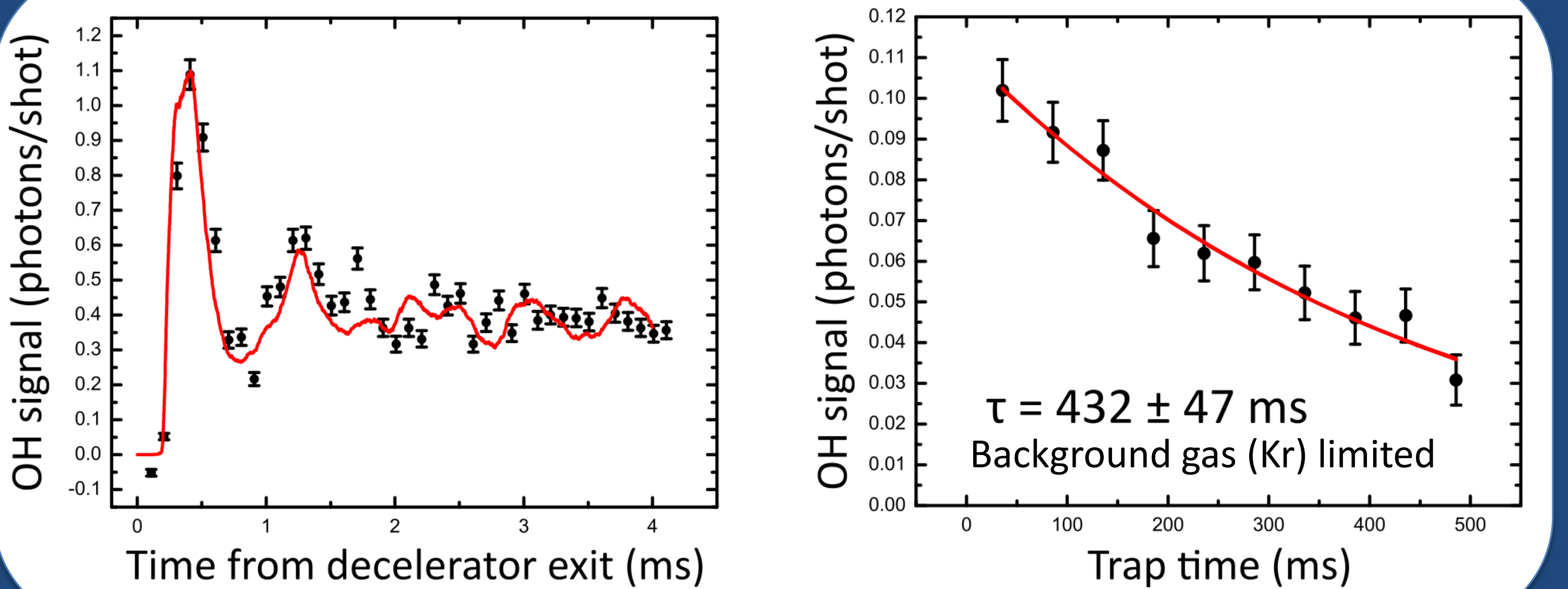
Electric Field lines



Magnetic trap loading



Magnetic trap loading



Evaporation of OH

- What do you need for Evaporation?
  - Selectively remove hot OH molecules from a trapped sample
  - Elastic collisions → rethermalization
    - Rethermalization rate >> loss rates
  - Characterize molecule number, temperature,
    - We can’t just turn our molecules back into atoms.
    - Microwave depletion spectroscopy

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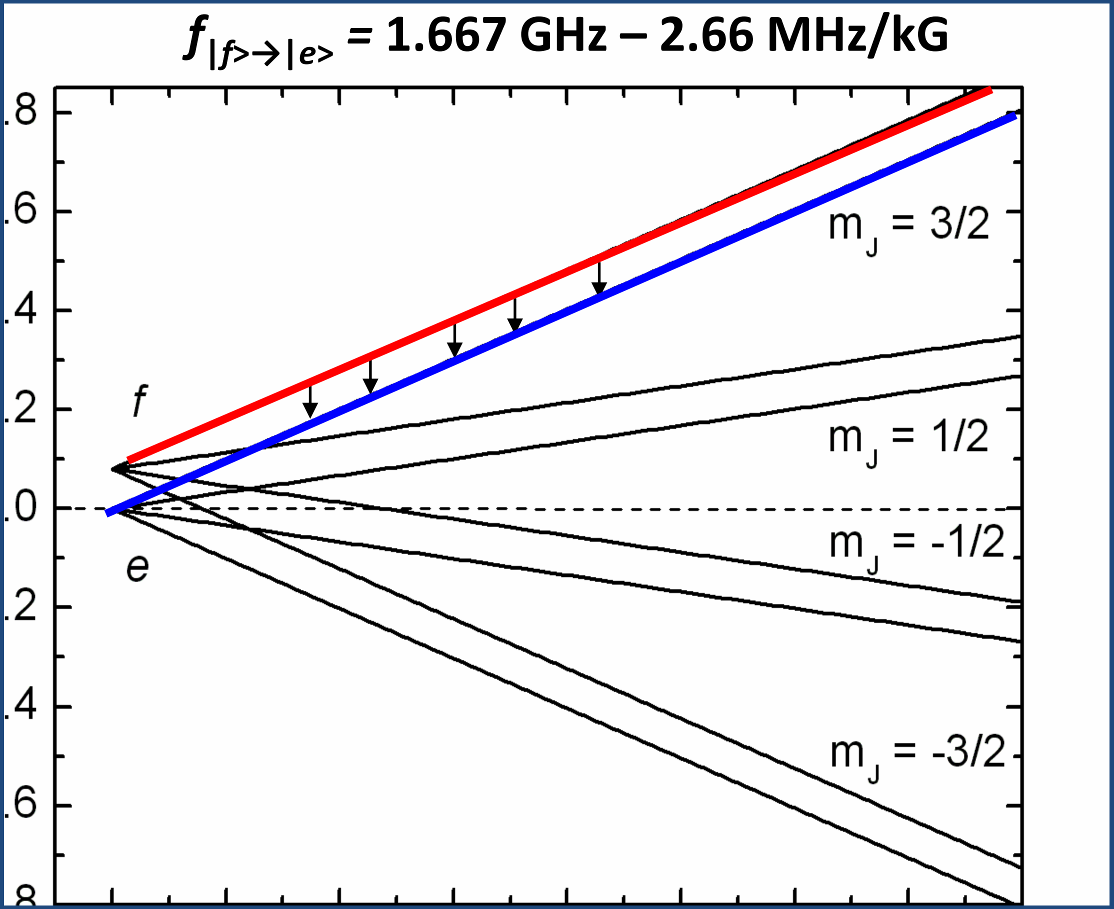
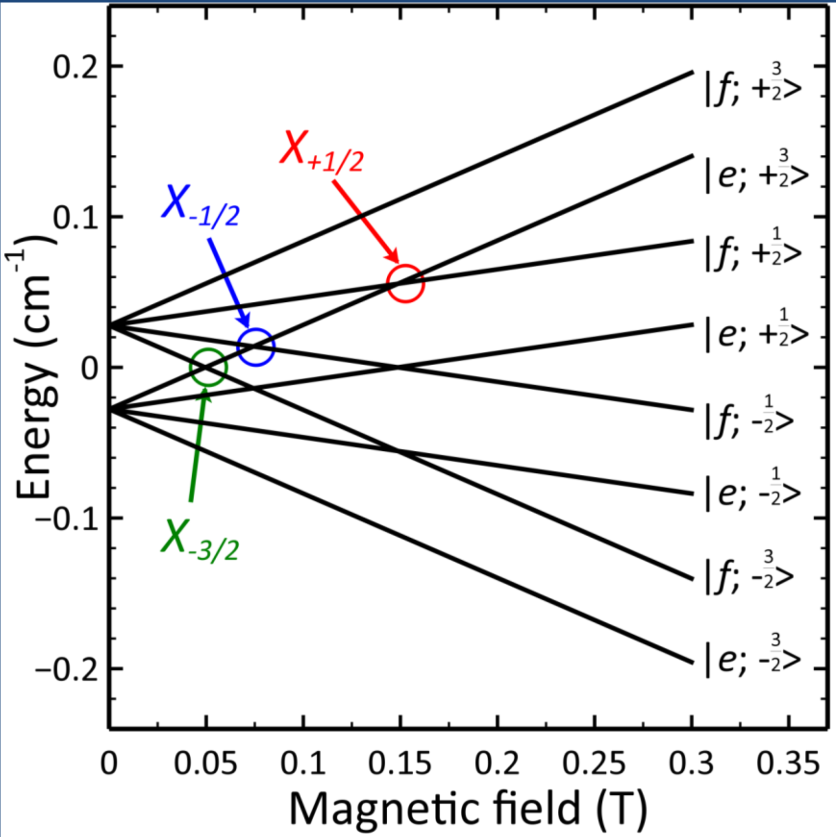
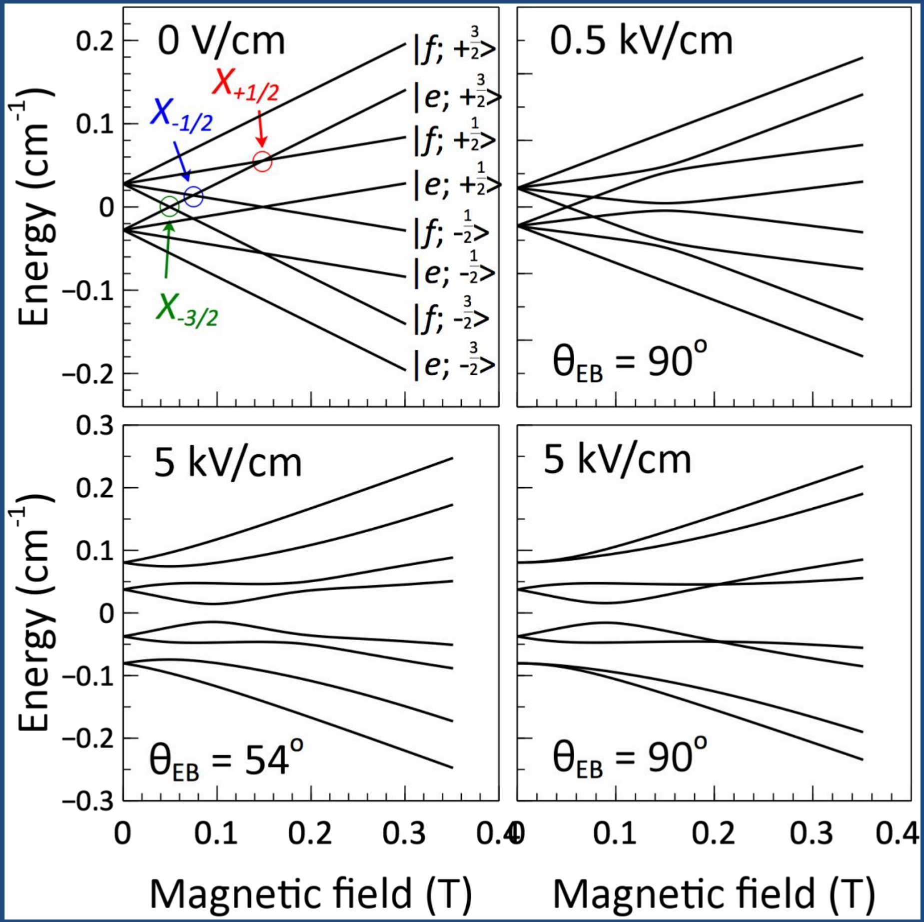
Controlling internal States



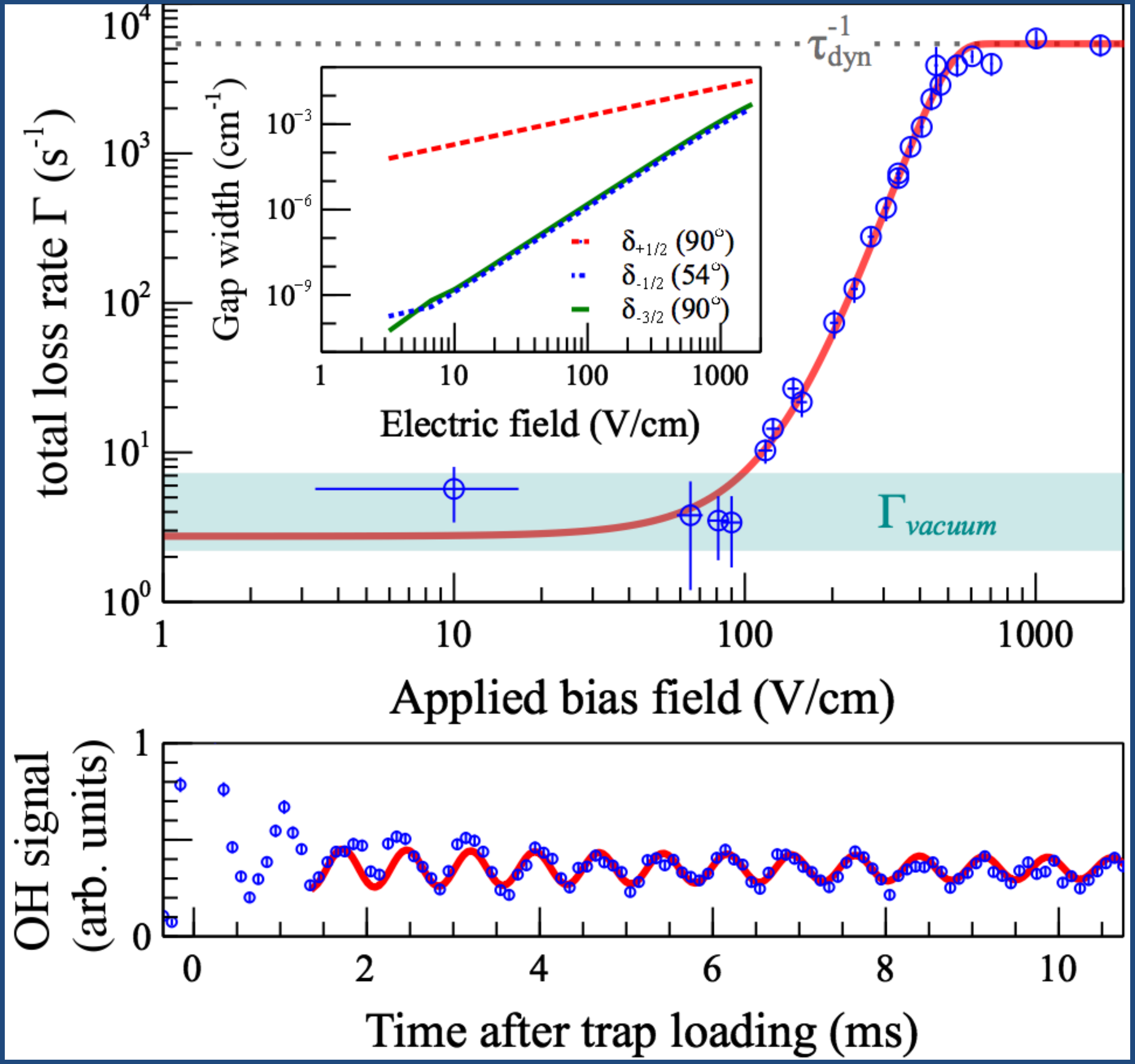
What happens to |e> molecules in the magnetic trap?



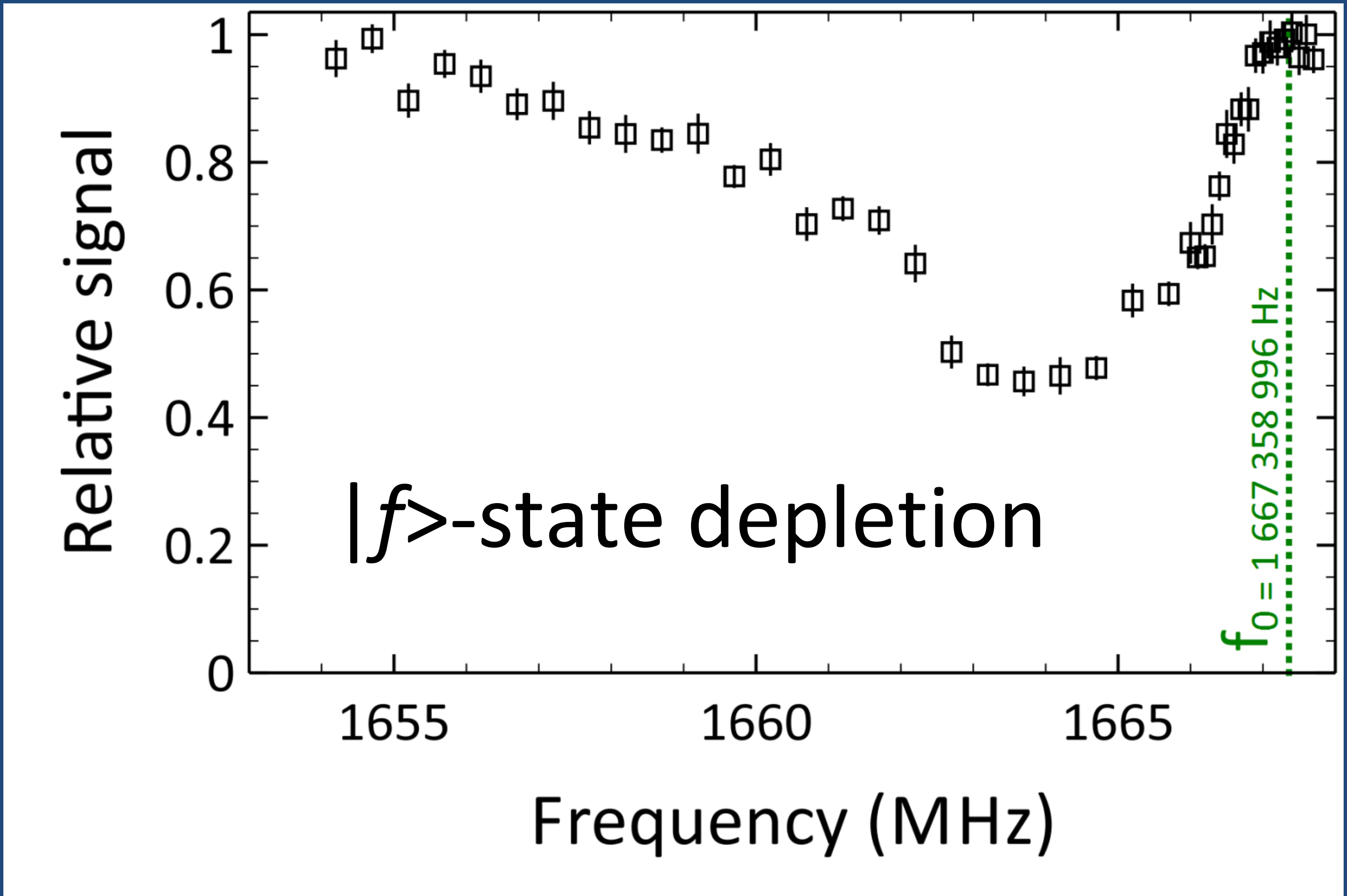


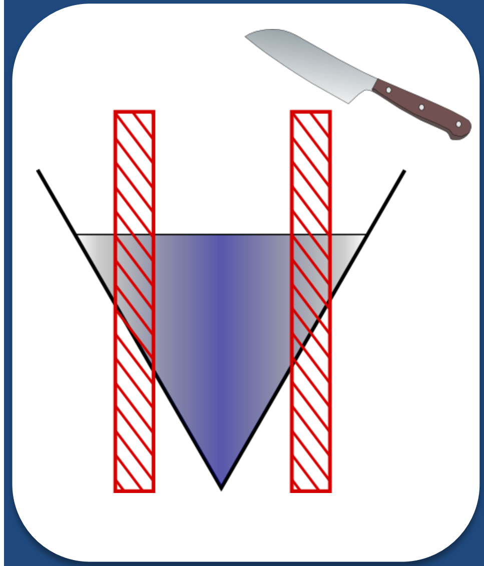
BKS, M. Yeo, B. C. Sawyer, M. Hummon, and J. Ye, *Phys. Rev. A* **85**, 033427 (2012)

Landau-Zener vs. |*e*>-state molecules

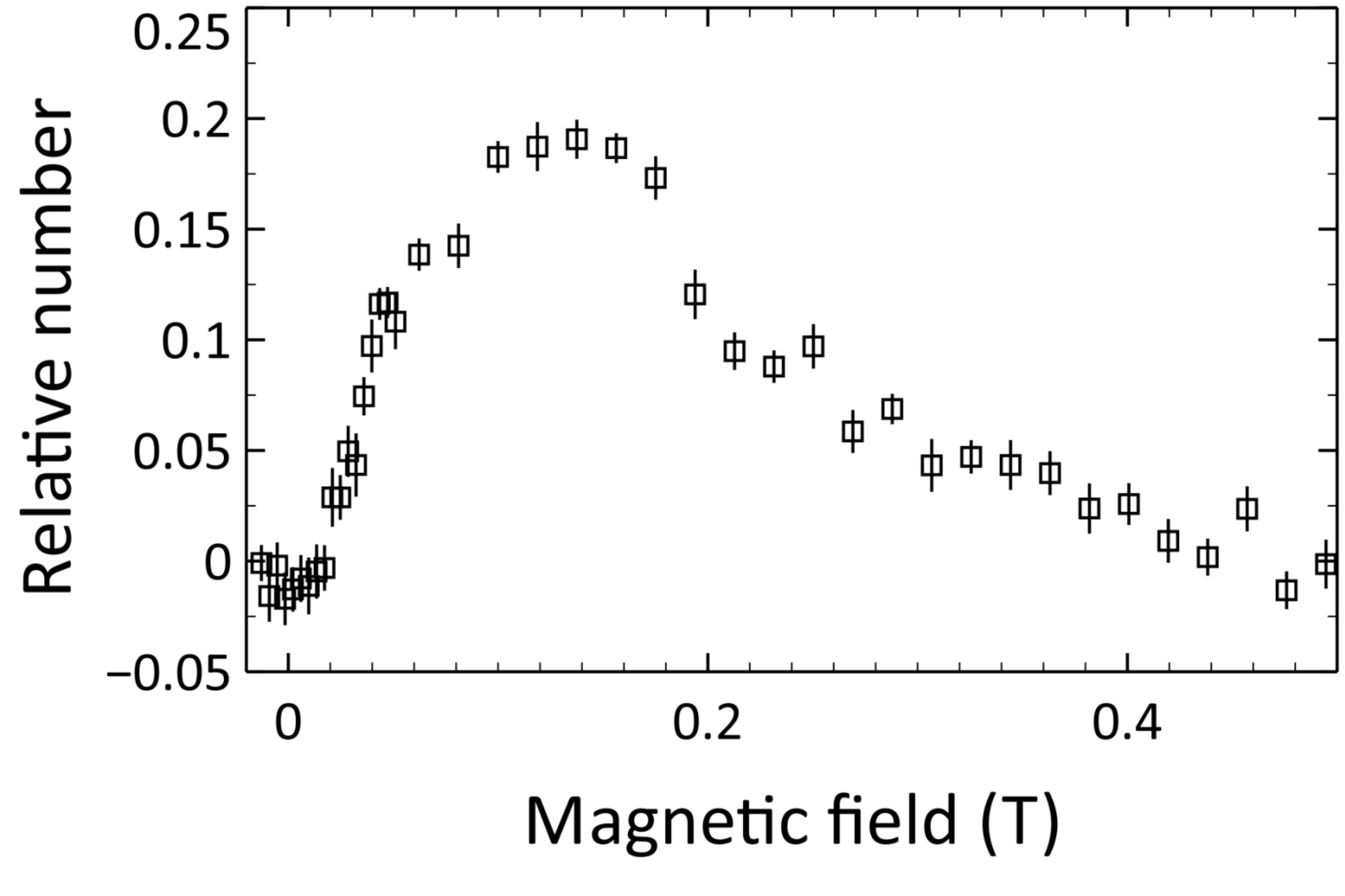


Thermometry through state control (I)

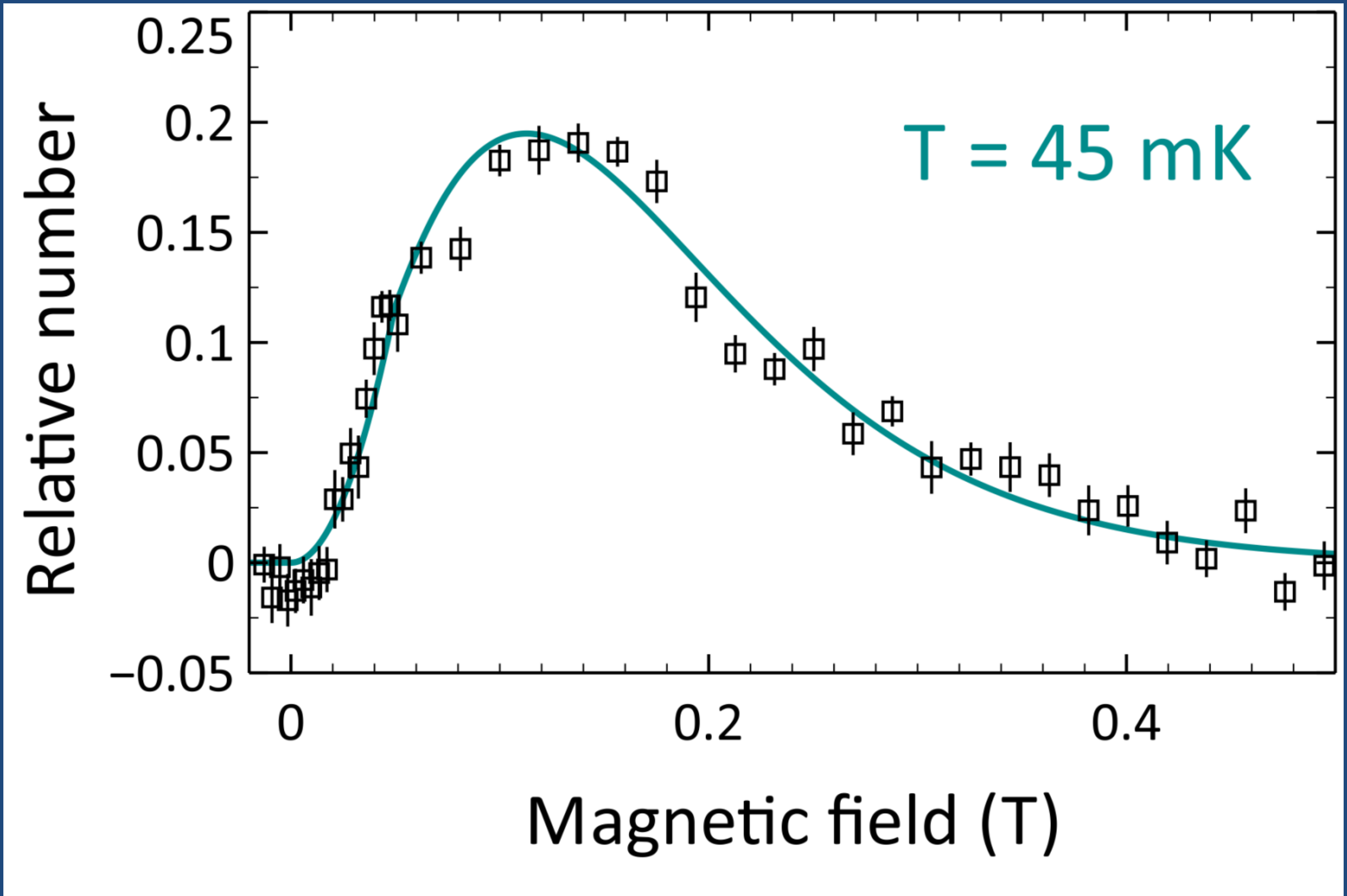




Thermometry through state control (II)



Thermometry through state control (III)



Evaporation of OH

- What do you need for Evaporation?
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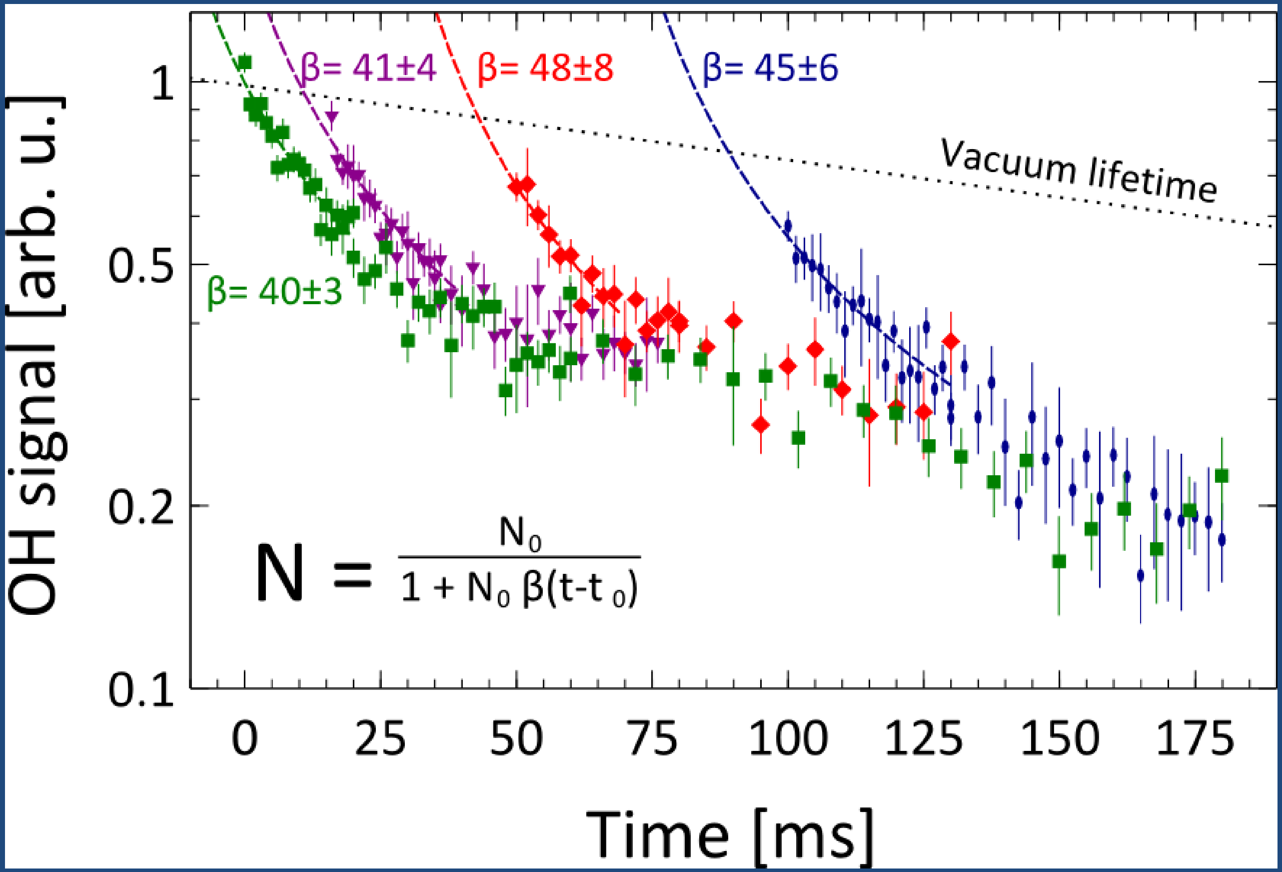
Electric field induced inelastic collisions

|*f*>-state two-body loss parameter β is independent of total number – but varies with electric field



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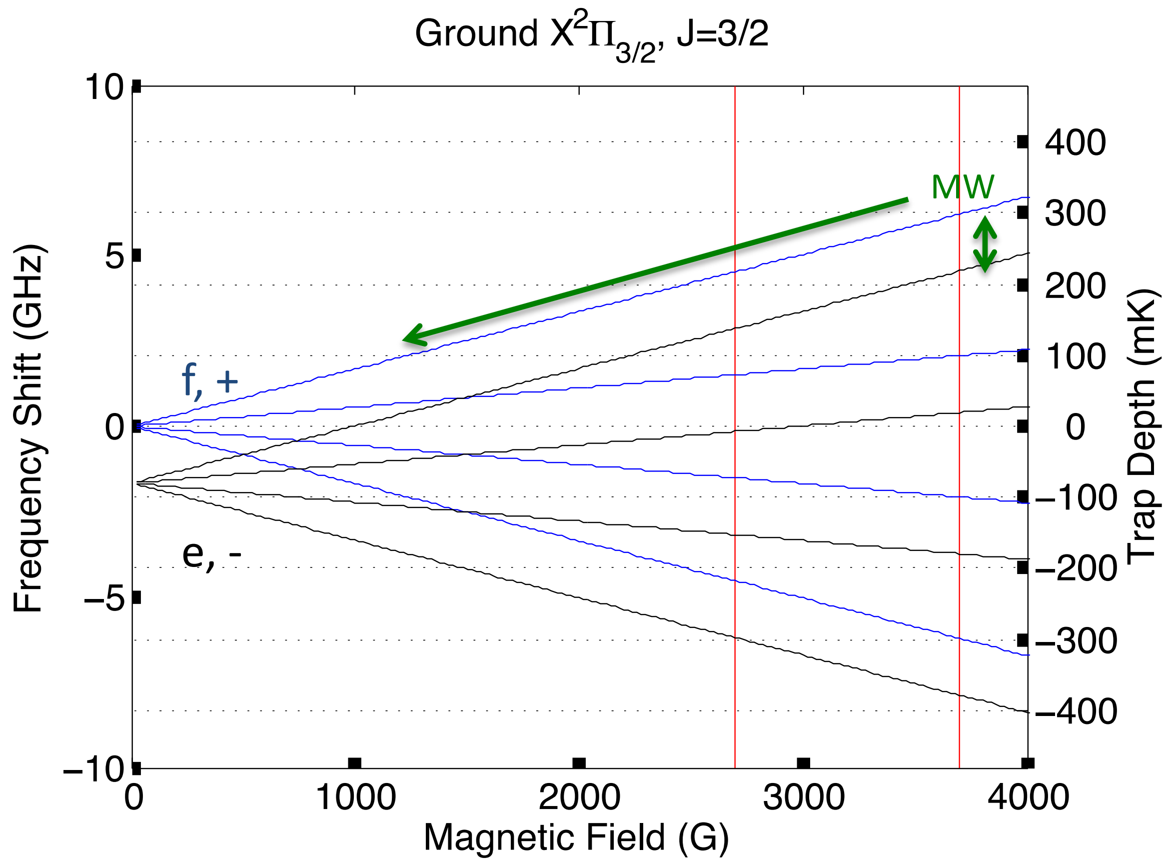
Evaporative cooling of OH

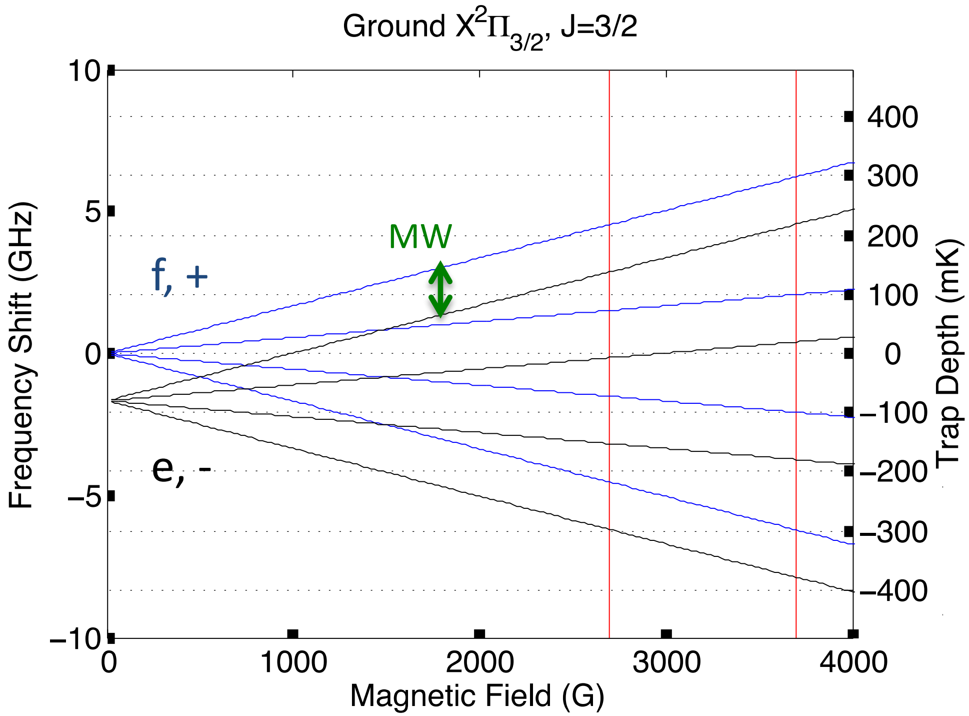


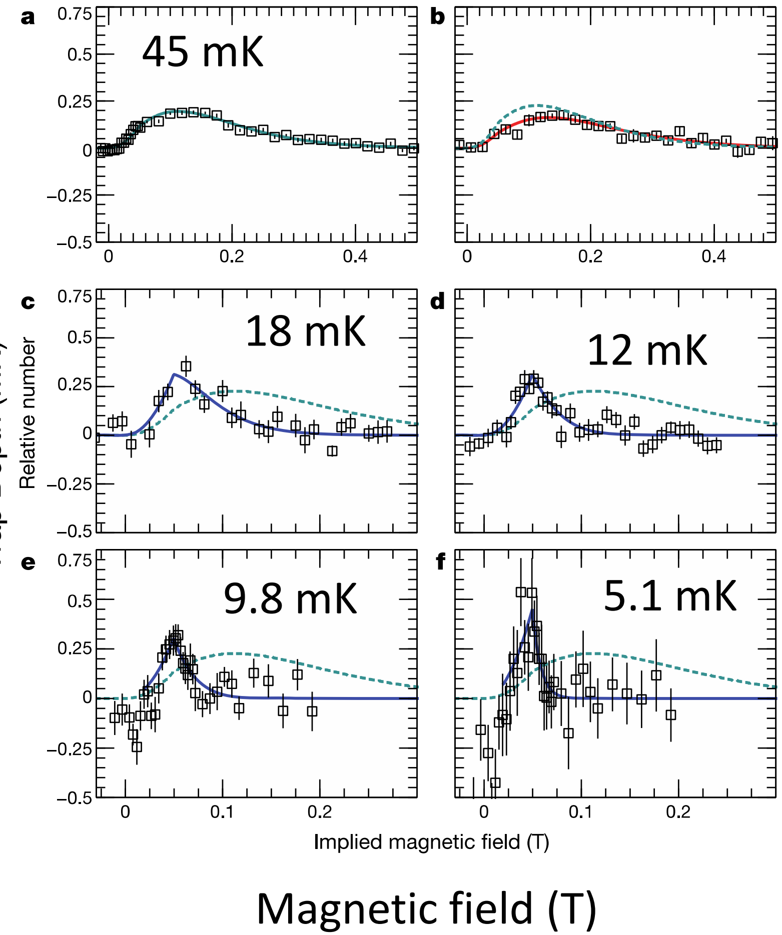
Transfer molecules from f, 3/2 -> e, 3/2 state.

e state molecules lost from trap.

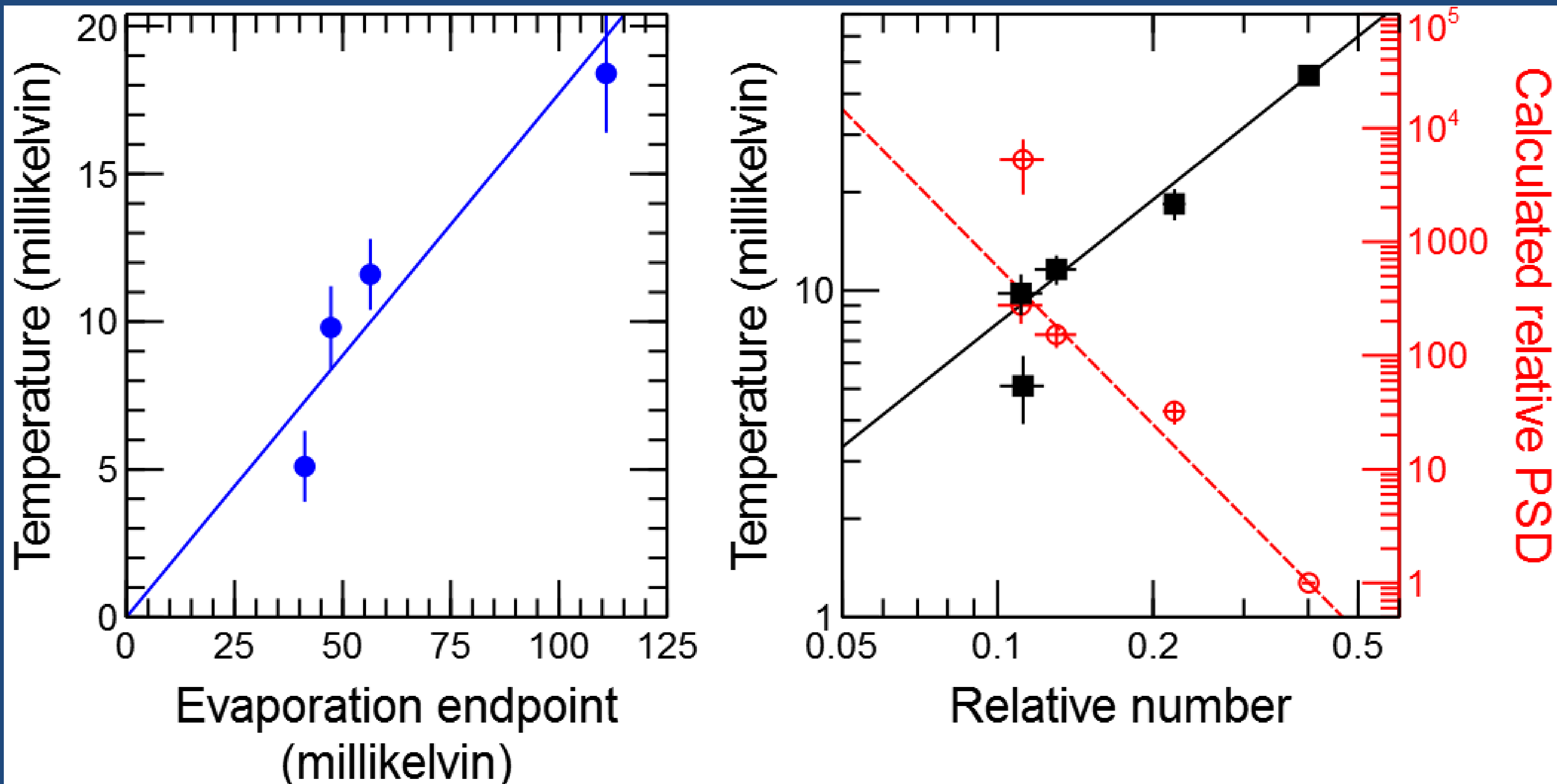
Sweep MF frequency to low temperature.

Evaporative cooling of OH





Efficiency of cooling

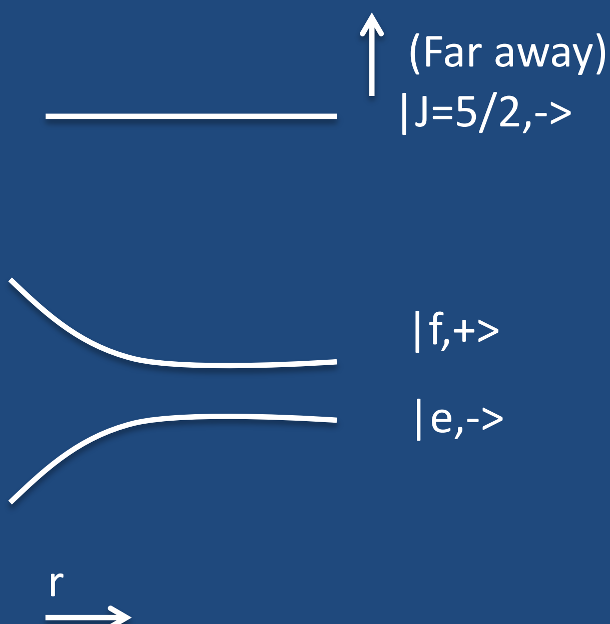


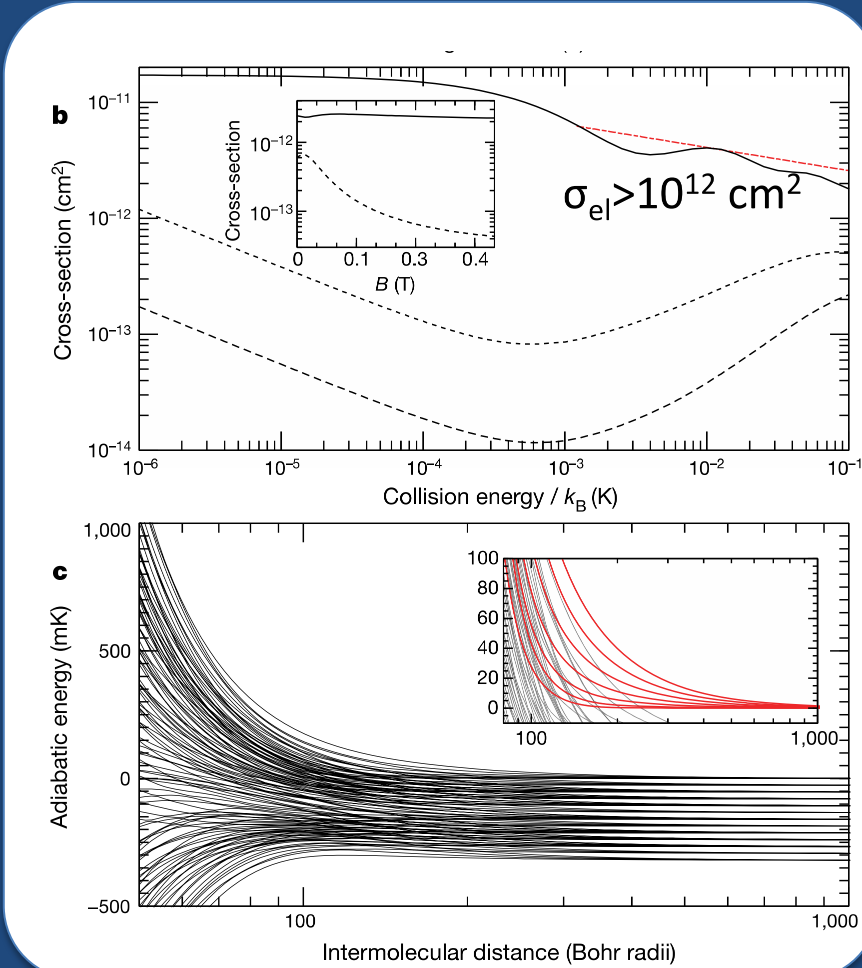
Why is the evaporative cooling so efficient?

Repulsive van der Waals interaction

Quéméner and Bohn

$$V_{\mathrm{vdW}}(r) = \sum_{n} \frac{|\langle m|V_{\mathrm{dd}}(r)|n\rangle|^2}{E_m - E_n} \equiv \frac{C_6}{r^6}$$

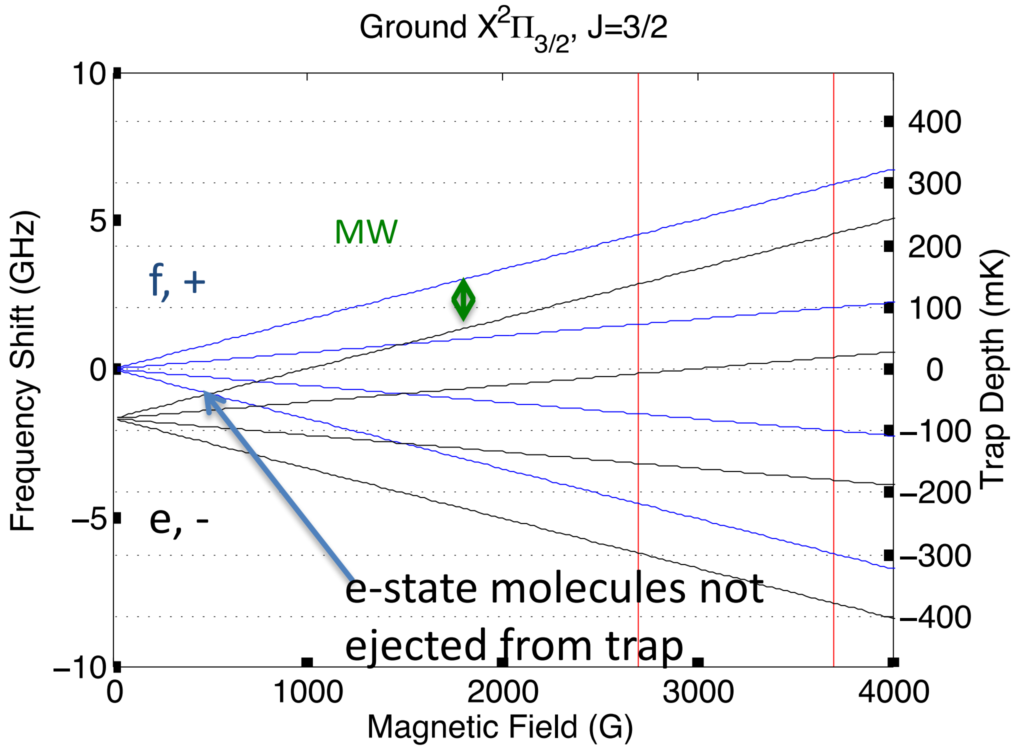




Conclusions for OH

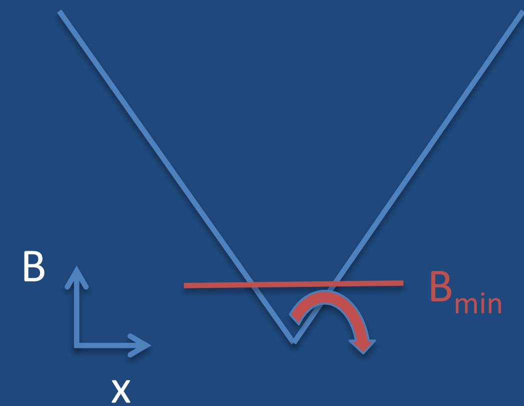
- Internal state control of OH key for manipulation
- Evaporative cooling from 50 mK → 5 mK
- 100x increase in phase space density
- Repulsive van der Waals suppresses inelastic loss
- Collisions rates of ~300 s^{-1}
- Inferred initial OH density 5 x 10^{10} cm^{-3}
- Inferred initial phase space density 3×10^{-10}
- Why stop at 5 mK?

Limitation to current evaporation



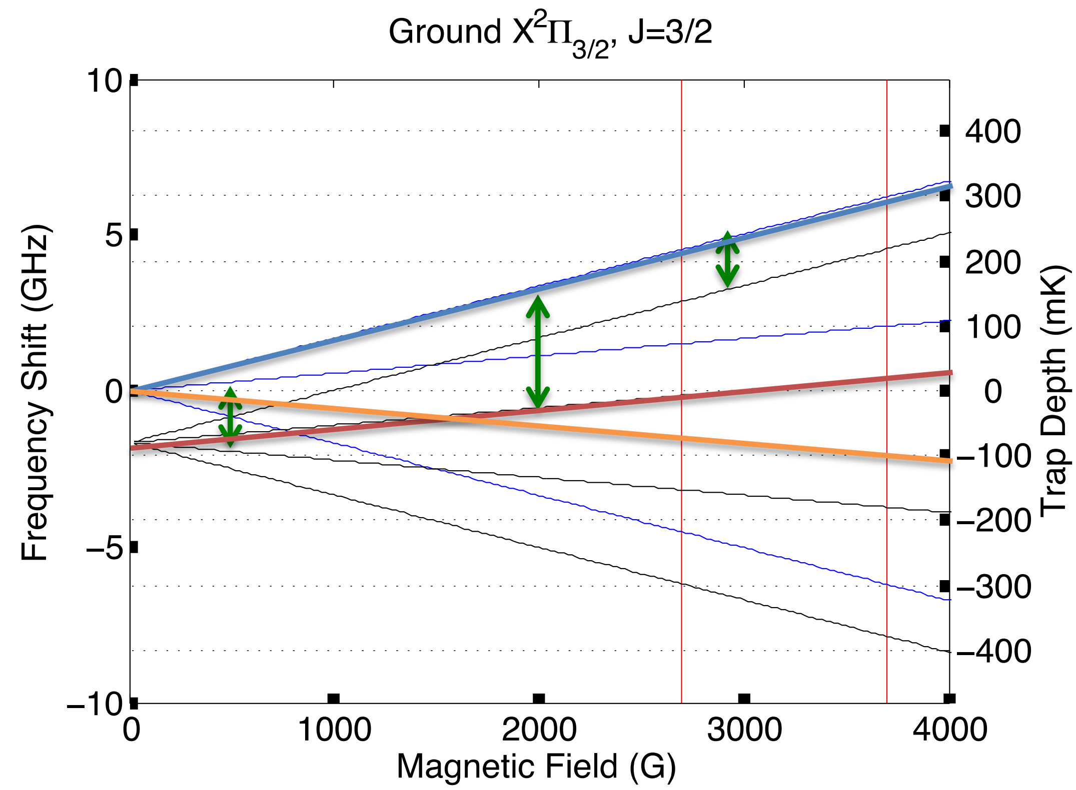
Future Directions for OH

- Evaporate to < 5mK
  - Investigate Majorana loss
  - Plug the hole with transverse electric field

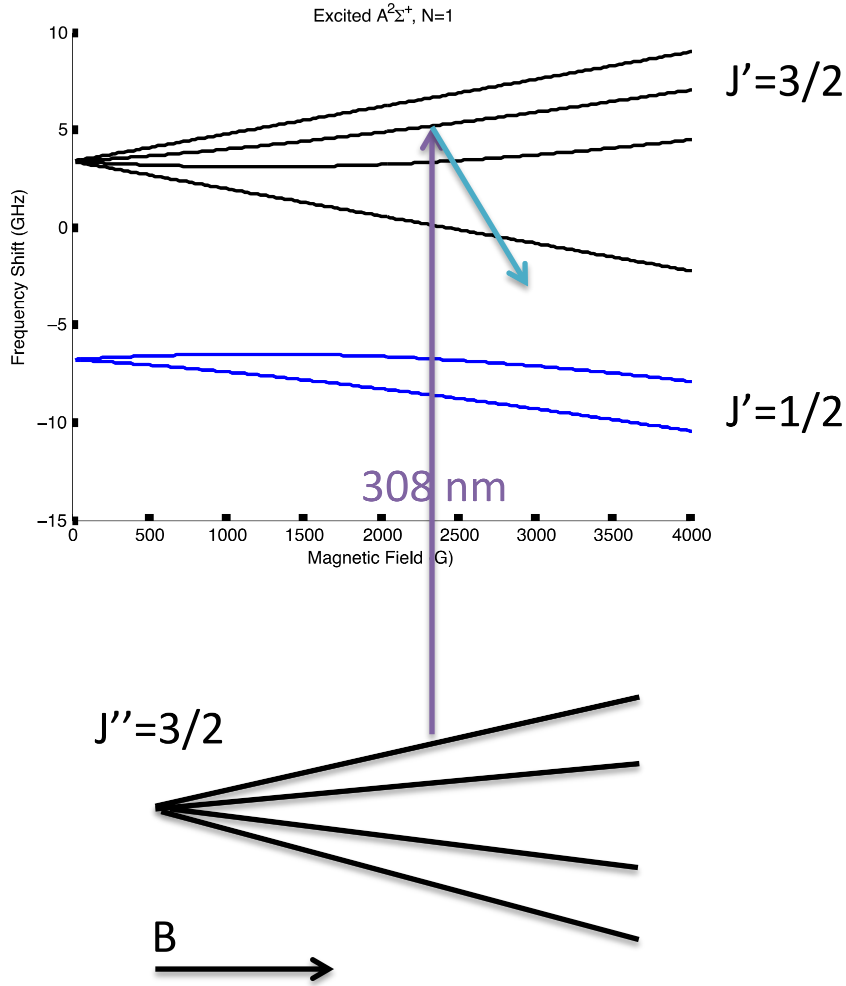


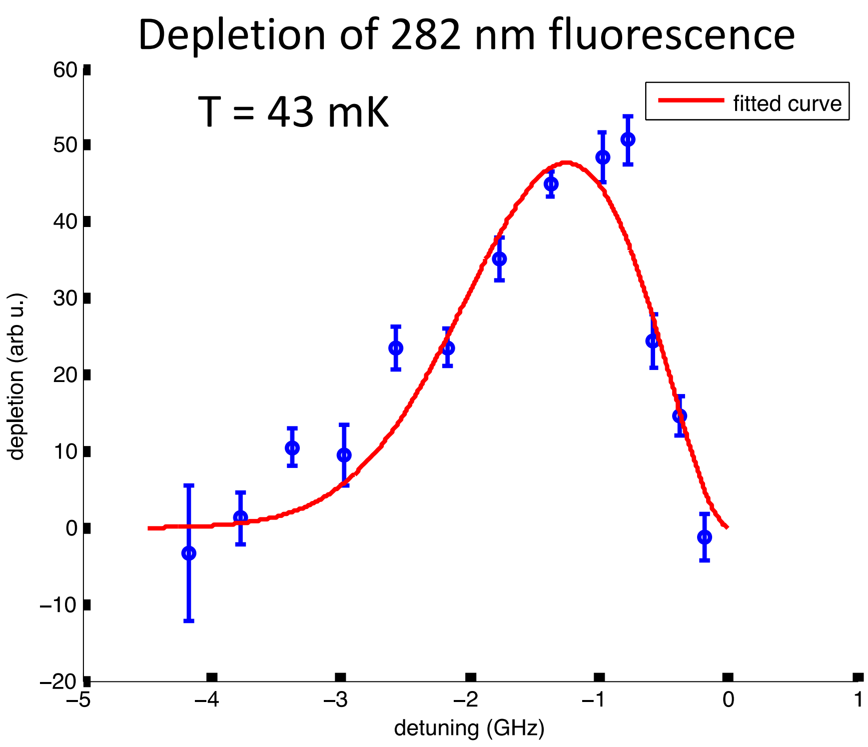
- Multi-step evaporation
- Optical depletion spectroscopy
- Lower temperatures should be possible

Multi-step evaporation

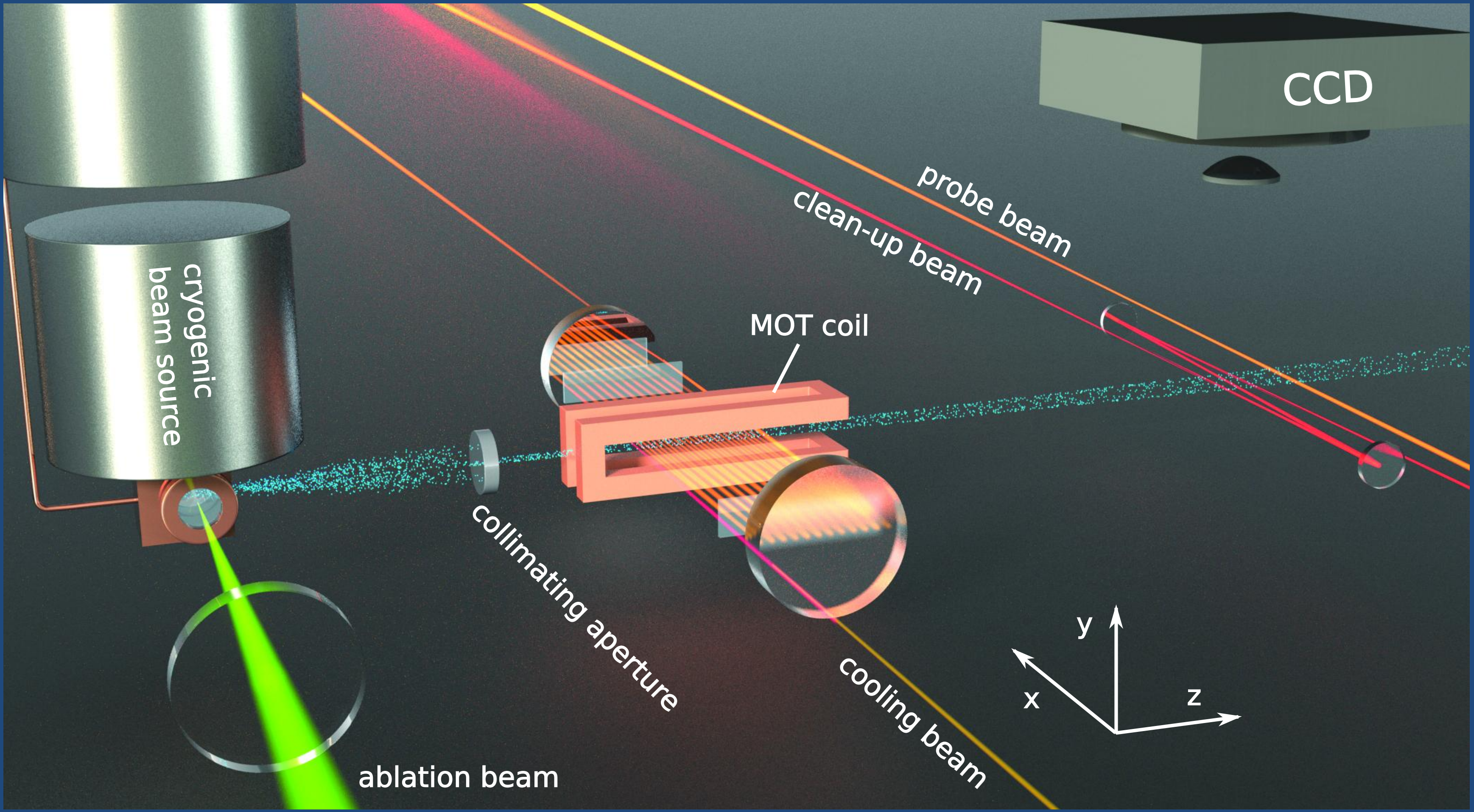


Optical Zeeman depletion spectroscopy





YO MOT apparatus



A cycling transition for YO

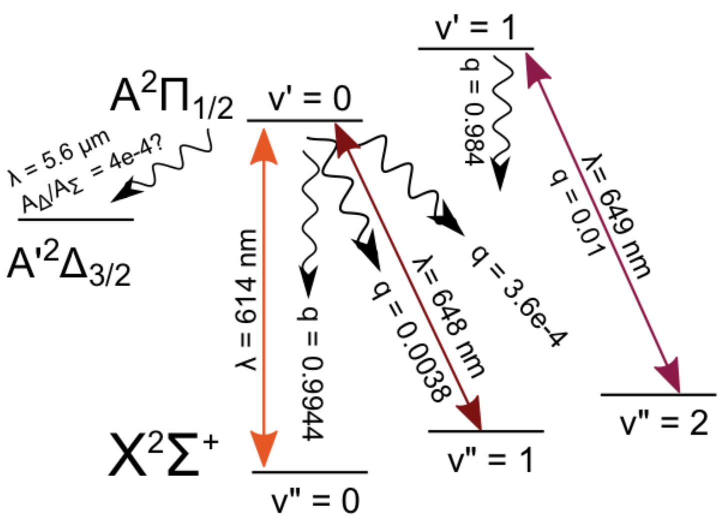
electric dipole moment: 4.5 D
magnetic dipole moment: 1 μ_B
rotational constant: 0.39 cm^{-1}

main cooling line: 614 nm
linewidth: $2\pi \times 5$ MHz
recoil velocity: 6 mm/s

YO beam velocity: 120 m/s

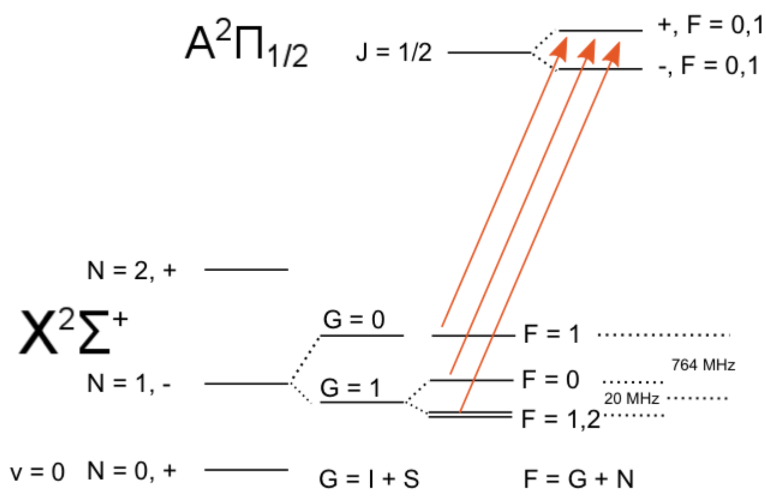
photon recoils to stop: ~10^4

YO vibronic structure



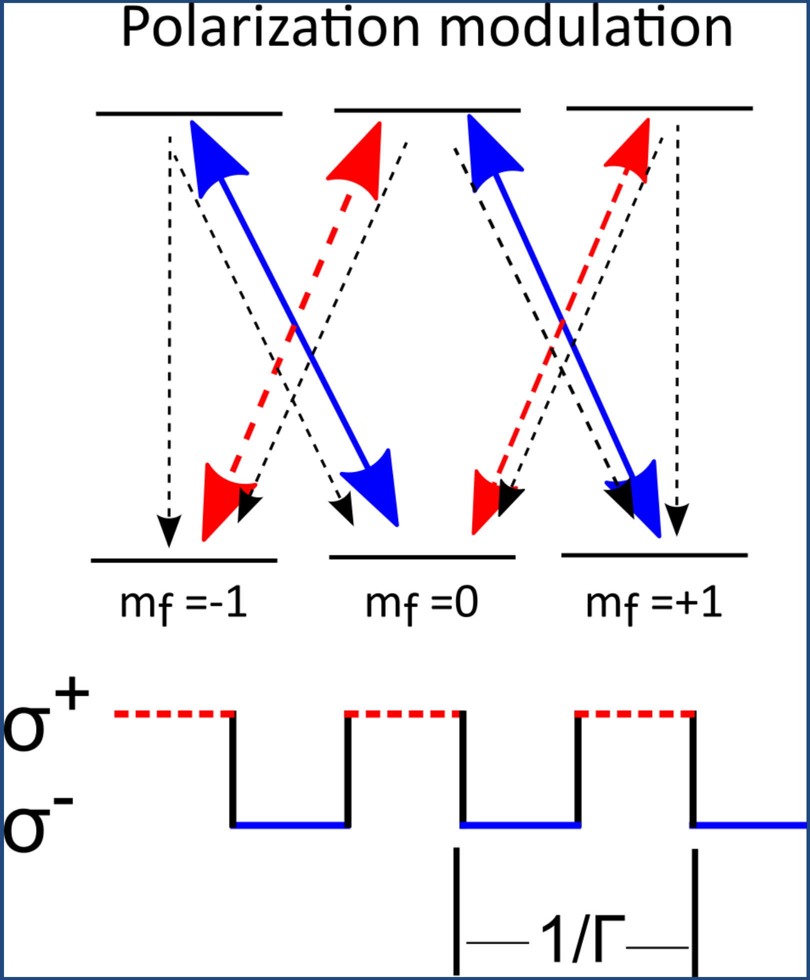
Bernard & Gravina, Astrophys. J. Suppl. **52**, 443 (1983).

YO rotational structure

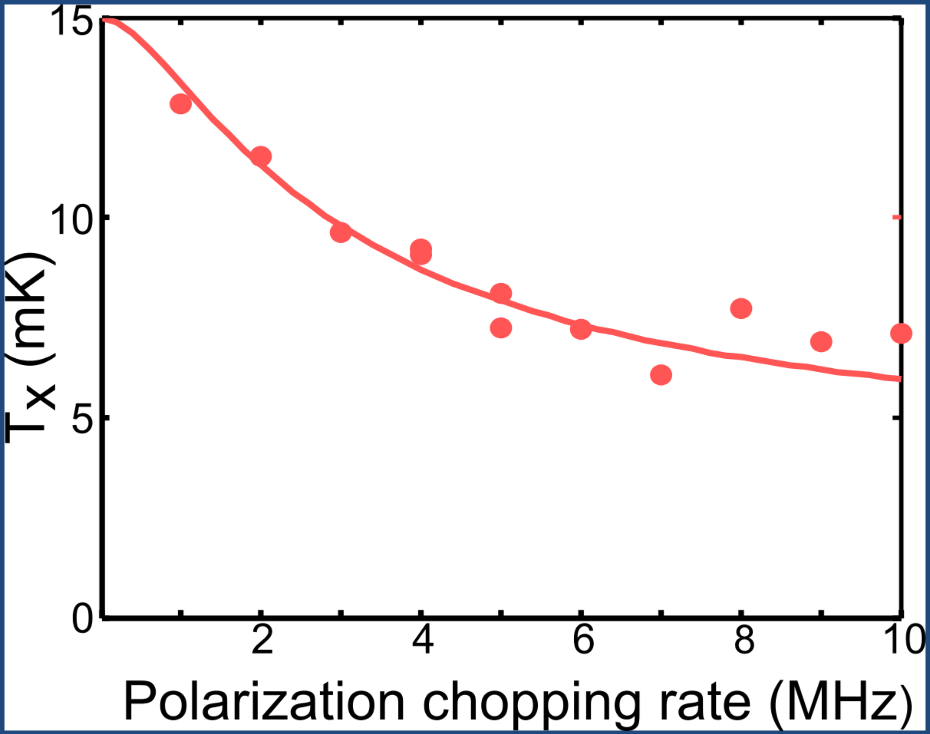


Childs, Poulsen, & Steimle, J. Chem. Phys. **88**, 598 (1988).

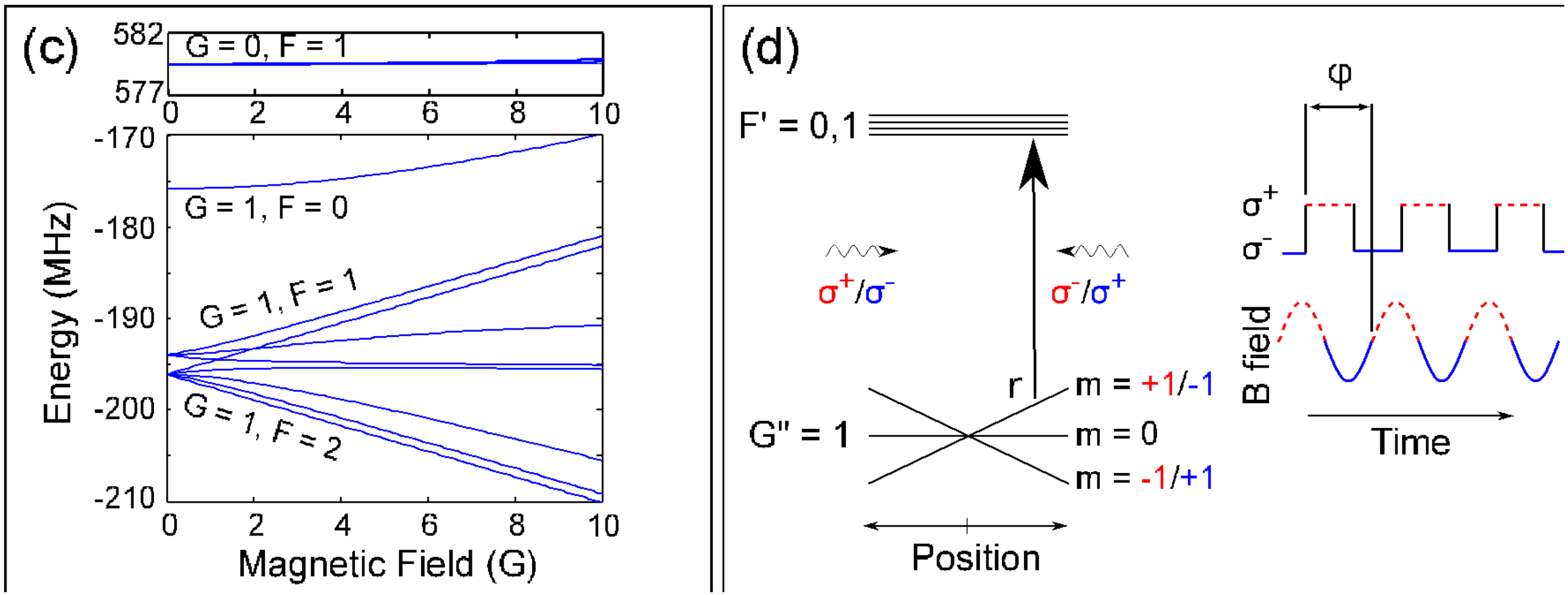
Remix Zeeman Dark States



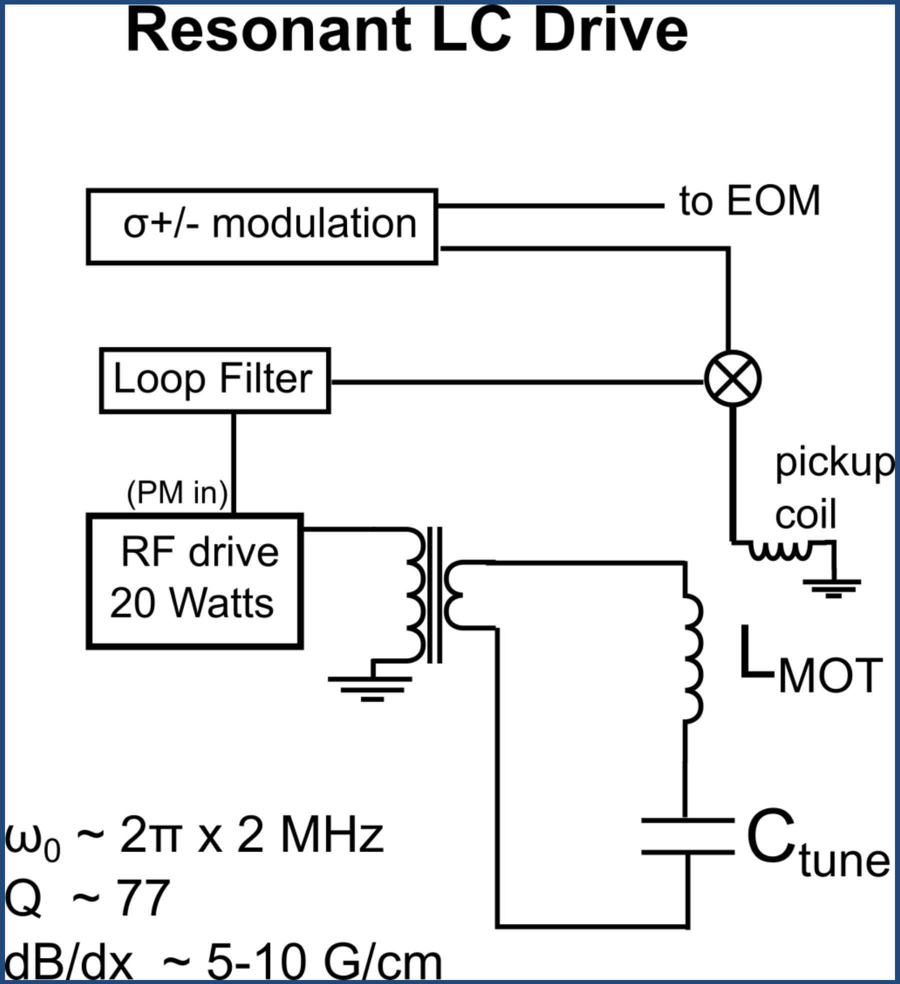
1-D Doppler cooling of YO

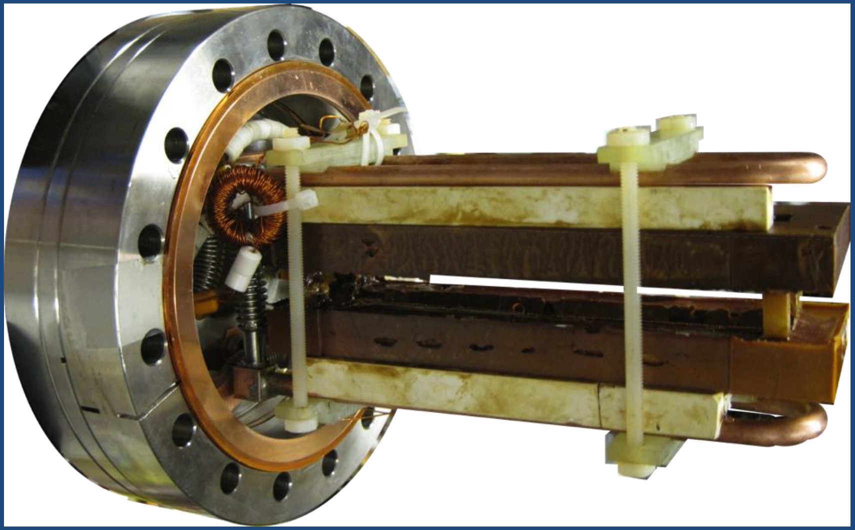


Generating a position dependent force

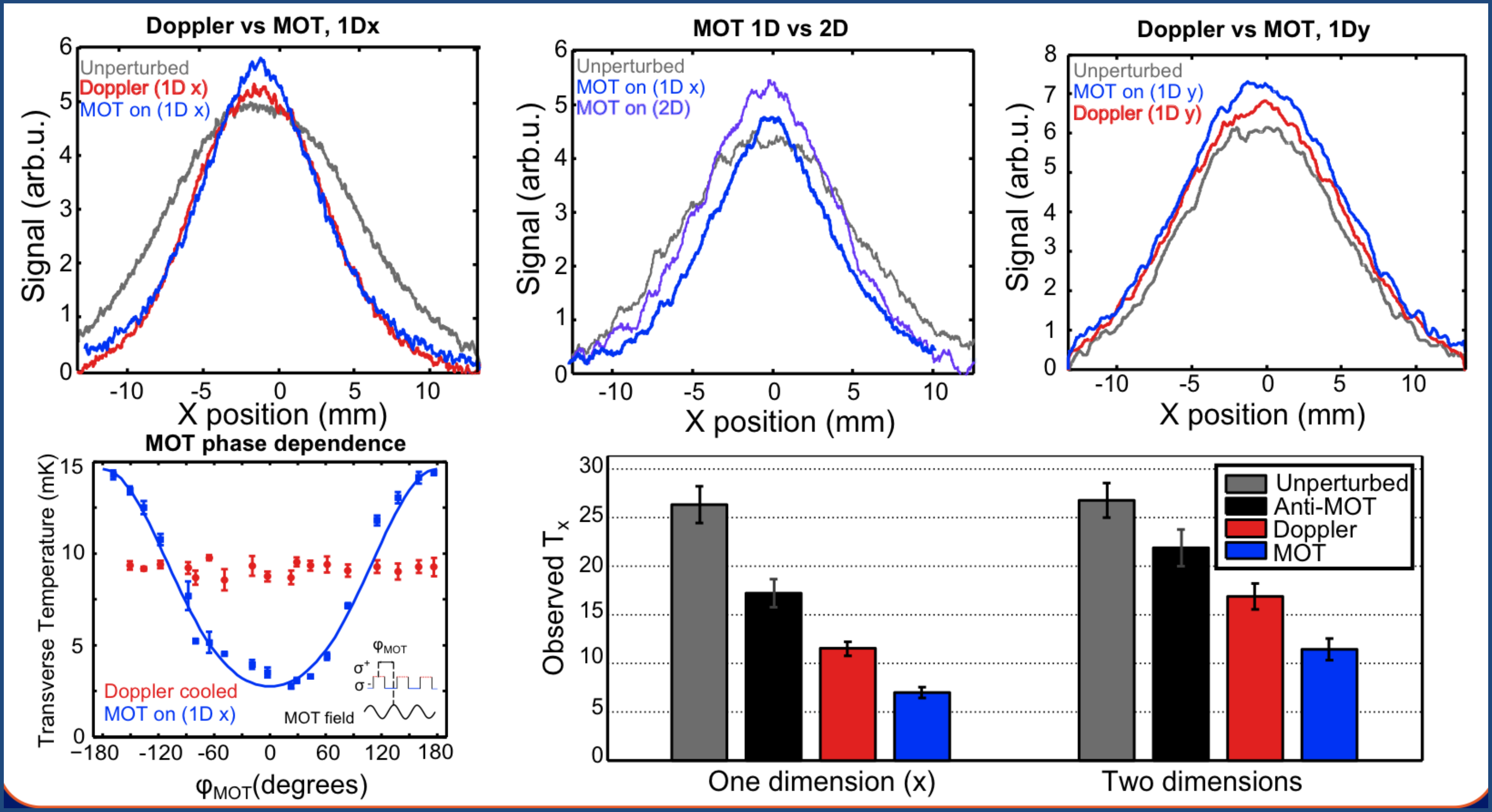


The Resonant 2D Mot Coils





YO MOT results



Atomic MOTs vs Molecule MOT

$$F/m = -(\Gamma/2)\, v - \omega^2 x$$

	YO MOT	Atomic MOTs
ω	$2\pi * 155$ Hz	Several kHz
Γ	$5*10^3\ s^{-1}$	$\sim 10^5\ s^{-1}$
$v_{caputre}$	10 m/s	~ 50 m/s

Torward a 3D MOT

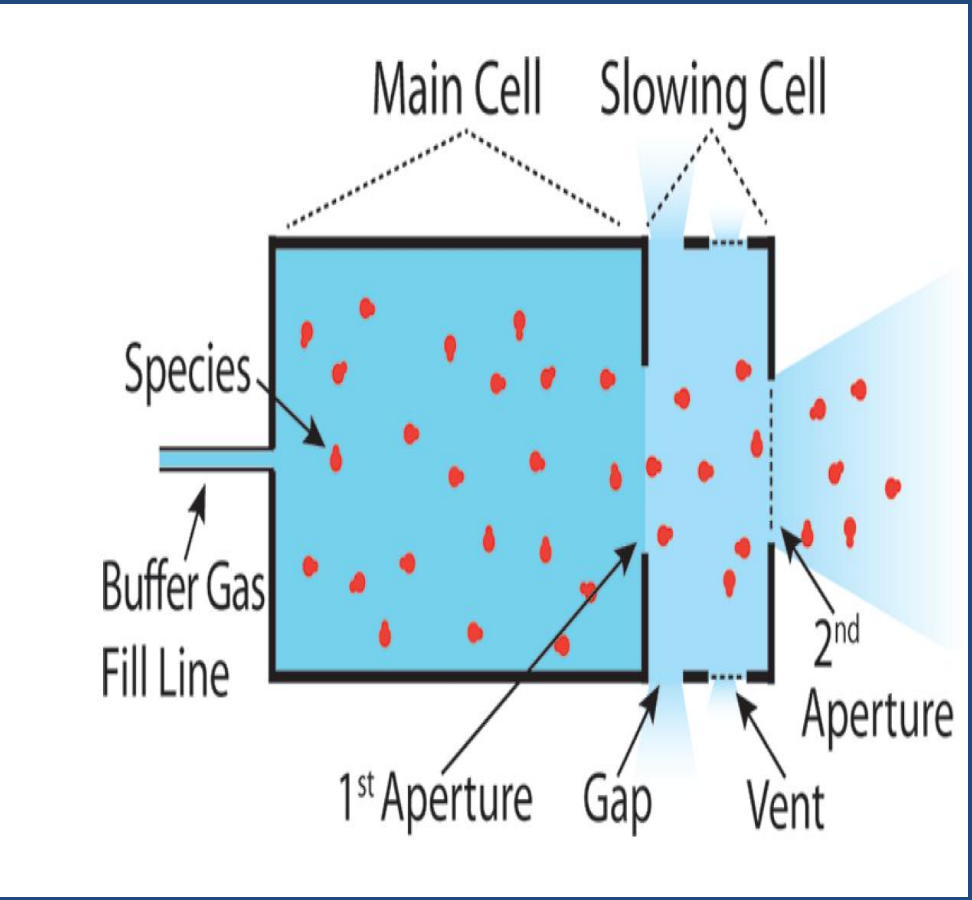
2-Stage, Slow buffer gas beam
(collaboration w/ J. Doyle, Harvard)

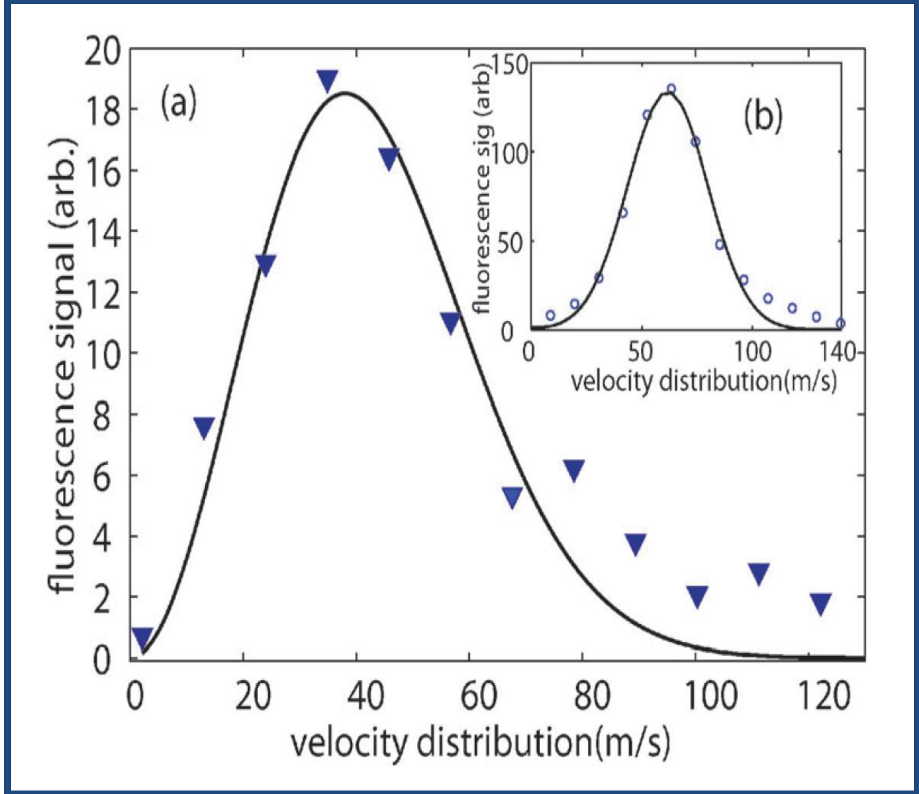
In vacuum 3D Resonant MOT coils

Conclusion

- Evaporative cooling of OH
  - 50 mK → 5 mK
  - 100x increase in phase space density
- A 2D MOT for YO
  - 25 mK → 2mK 1D transverse cooling
  - Interaction time limited temperature
  - 10 m/s capture velocity expected for 3D MOT

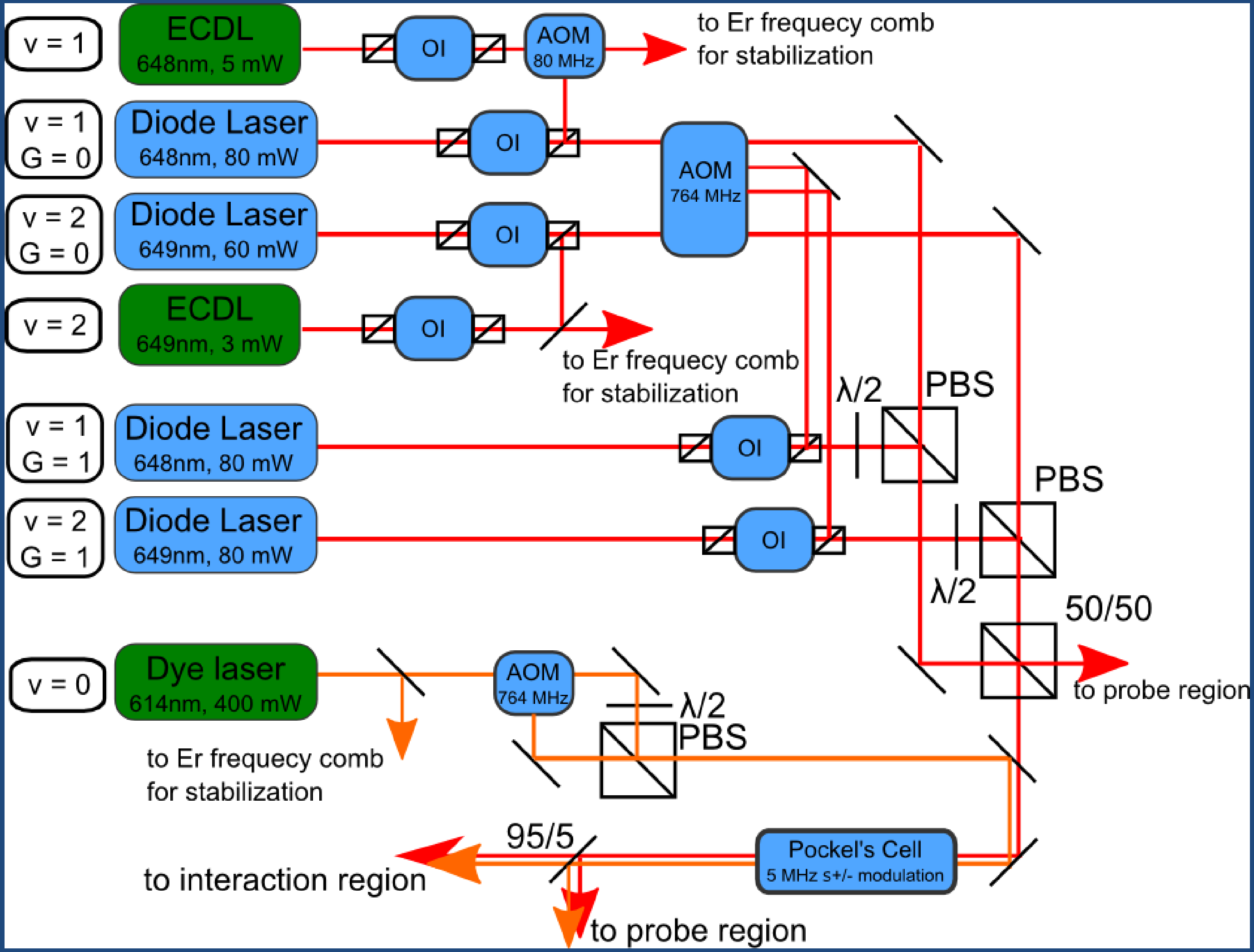
The Slowing Cell



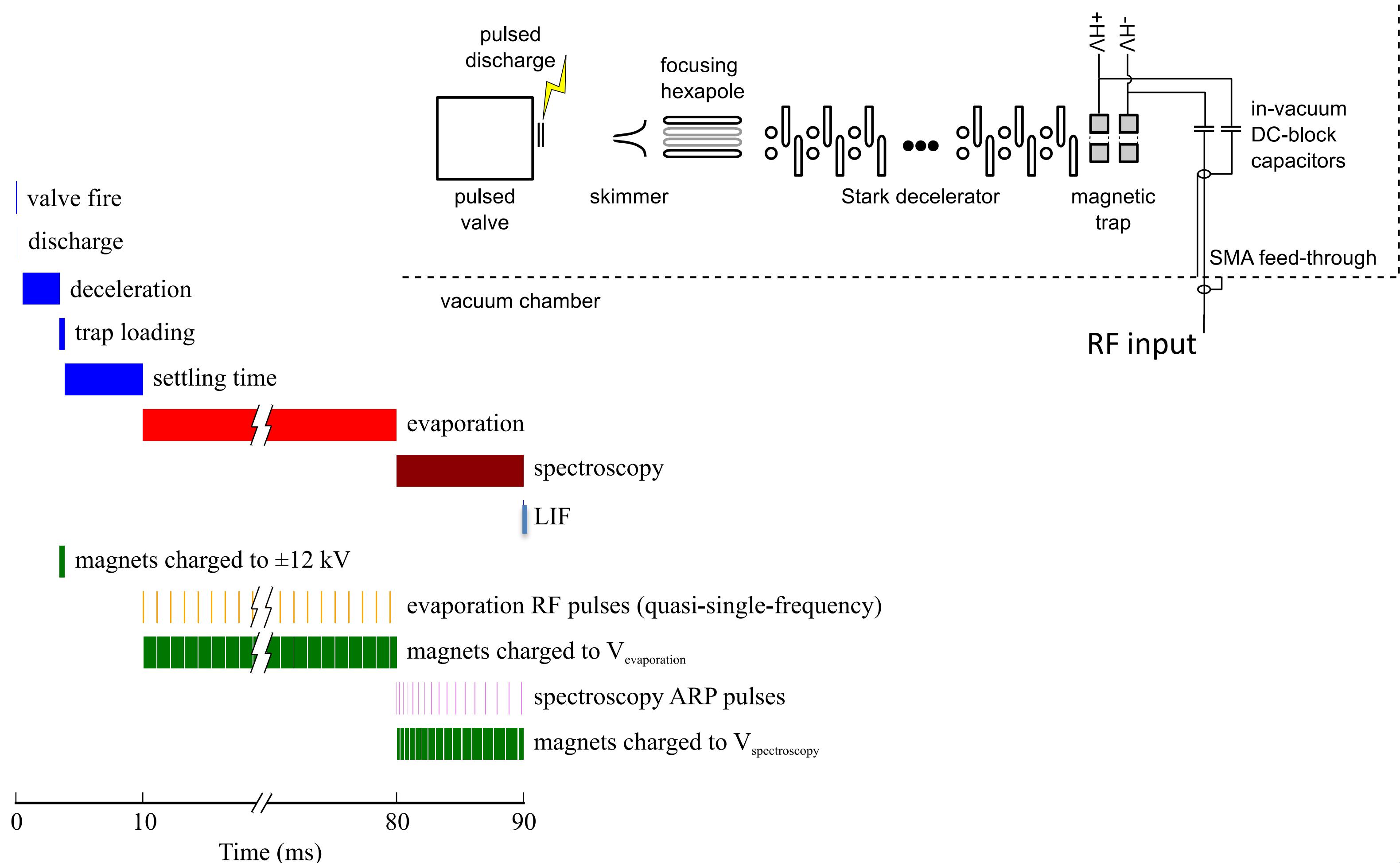


N.R. Hutzler, H. Lu and J. M. Doyle, *Chem. Rev. In press* (2012)
H. Lu, J. Rasmussen, M.J. Wright, D. Patterson and J.M. Dolye, PCCP, 2011.13.18986-18990

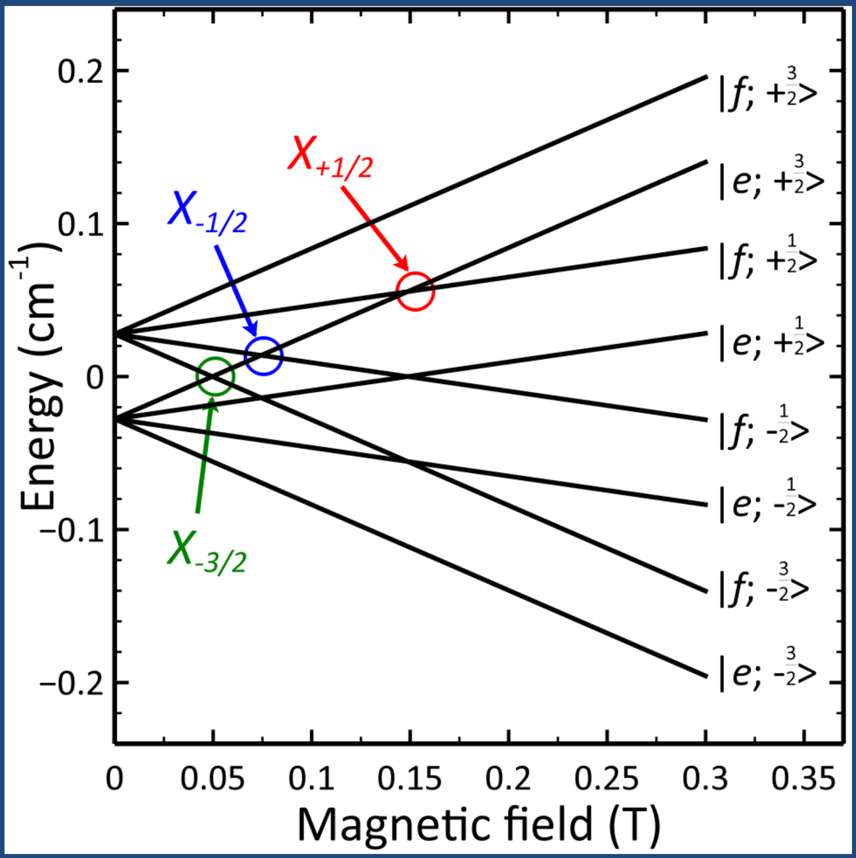
Cooling lasers for YO



Experimental sequence for evaporation



What's that funky line shape?



If the |e>-state molecule can't escape the trap, we don't see the loss!

$$N(B)dB \propto B^2\, dB\, e^{-\mu B/kT} \times \begin{cases} 1 \text{ if } B > X_{-3/2}, \\ e^{-\mu(X_{-3/2} - B)/kT} \text{ else} \end{cases}$$